









Electrochemical cells and components thereof

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Abstract of EP0991133

An electrochemical cell (10), typically an air depolarized cell of the button-type has non-reactive elements significantly thinner than corresponding non-reactive elements of prior art cells. Such elements are thinner thanks to improved structures of such elements. Among these elements is an anode can (24) which is made from a metal strip structure having a high steel content. Another element is the cathode can (40) which has a modified temper and improved relative stiffness and rigidity,

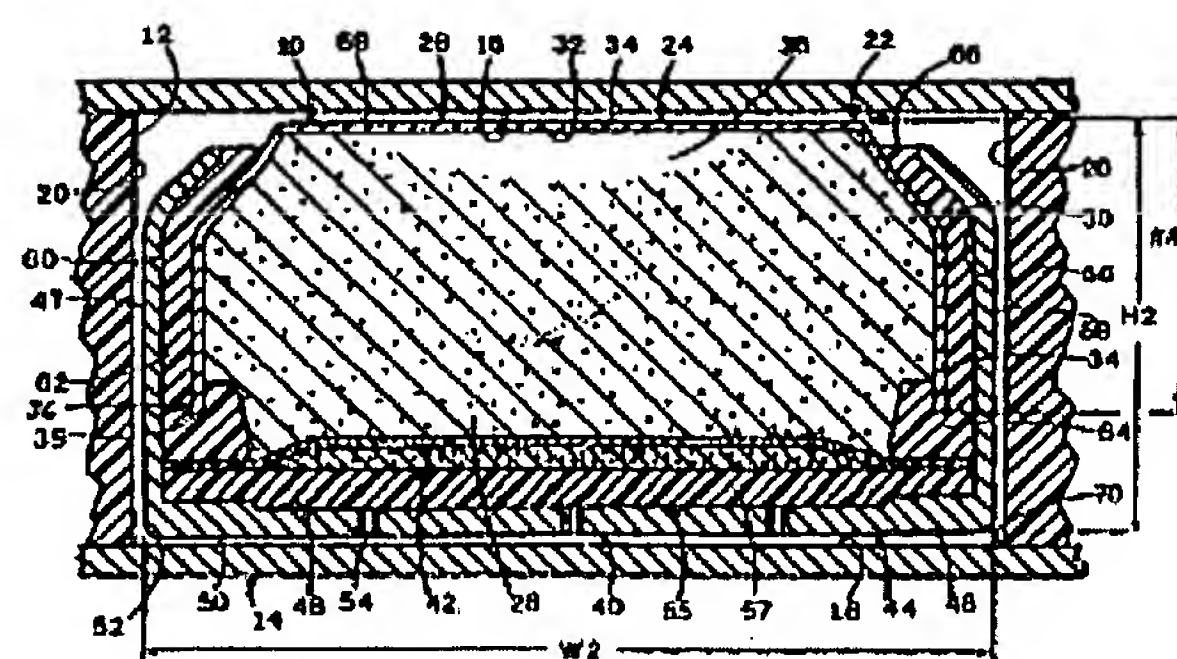


FIG. 2

while retaining sufficient ductility to tolerate forming the cathode can. By so reducing the thicknesses of non-reactive elements of the cell (10), and thus the volume occupied by such non-reactive elements, the fraction of the volume of the cell (10) devoted to holding electrochemically reactive anode material (26) therein is increased, yielding a corresponding increase in the milliampere hour capacity of the cell.

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(54) Title: PLATE FOR HOUSING AND/OR LIDS FOR BUTTON CELLS AND PROCESS FOR MANUFACTURING SUCH A PLATE

(57) Abstract: The invention relates to a plate for producing housings and/or lids for button cell batteries, comprising a core layer of steel, a copper or nickel clad top layer at one side of the core layer and a nickel top layer at the other side of the core layer. The invention is characterized in that the nickel top layer has been applied by depositing the nickel and in that the core layer has a thickness from 0.10 to 0.5 mm. The invention also relates to a housing and lid for a button cell battery fabricated from such a plate, and to a process for manufacturing such a plate.

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PLATE FOR HOUSINGS AND/OR LIDS FOR BUTTON CELLS AND PROCESS FOR MANUFACTURING SUCH A PLATE

The invention relates to a plate for producing housings and/or lids for button
5 cell batteries, the plate comprising a core layer of steel, a copper or a nickel
top layer at one side of the core layer and a nickel top layer at the other side
of the core layer. The invention also relates to a housing or lid for a button
cell fabricated from such a plate, and to a process for manufacturing such a
plate.

10 Housings and lids for button cell batteries are presently made from a
stainless steel core layer having a clad nickel layer on the outside and a clad
copper layer or clad nickel layer on the inside of the battery. The clad nickel
layer on the outside of the housing and lid is present because the contact
resistance of stainless steel is too high for battery purposes. Nickel is chosen
15 in view of the outside appearance of the button cell battery. The clad copper
layer is present on the inside of the housing or lid because the anode
material (e.g. zinc powder with an alkaline electrolyte) in the button cell that
contacts the housing or lid is chemically very aggressive and attacks metals
other than pure copper by generating hydrogen, which could cause serious
20 damage of cell due to explosion. A specifically chosen copper quality
provides hydrogen overvoltage to prevent hydrogen generation. The clad
nickel layer is present on the inside of the lid or housing because air holes of
the button cell are exposed to aggressive chemicals and must be protected
to ensure the foreseen lifetime of the battery. Currently stainless steel is
25 used as core material in view of corrosion and strength requirements of the
battery manufacturer.

The above described plate material of stainless steel core material with
clad nickel and/or copper top layers has been used for a long time for
producing housings and lids for button cell batteries. However, it has the
30 drawback that this plate material is rather expensive.

It is an object of the invention to provide a plate for producing housings
and/or lids for button cell batteries that is cheaper than the known stainless

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steel clad products for producing such housings and/or lids. It is another object of the invention to provide a process for manufacturing such plates.

According to a first aspect of the invention there is provided a plate for producing housings and/or lids for button cell batteries, comprising a core layer of steel, a copper or nickel clad top layer at one side of the core layer and a nickel top layer at the other side of the core layer, wherein the nickel top layer has been applied by depositing the nickel and wherein the core layer of steel has a thickness from 0.10 to 0.5 mm.

In comparison with the known stainless steel copper and/or nickel clad product the plate according to the invention has the advantage that the nickel layer that will form the outside of the housings and/or lids has not been clad on the core layer, but that the nickel has been deposited. Cladding is an expensive process, because a thin nickel foil must be rolled onto the core layer. The thin nickel foils are very expensive. To deposit nickel on a substrate is a process that is easier and cheaper. The core material has a thickness from 0.10 to 0.5 mm in view of the strength requirements of the battery manufacturer.

According to a preferred embodiment of the plate according to the invention, the nickel layer has been applied by plating, preferably electrolytic strip plating. Electrolytic strip plating is a well-known process for coating a substrate and forms a thin and well-defined layer on a substrate. Usually the nickel layer thus formed is not as pore-free as a clad layer because pin-holes can be present. According to the invention a sufficient thick nickel layer is deposited to ensure a pin-hole free nickel layer, which is rolled and diffusion annealed to provide a dense, homogeneous, ductile and corrosion resistant nickel/iron layer.

According to another embodiment of the plate according to the invention, the nickel layer has been applied by Physical Vapour Deposition (PVD) or by Chemical Vapour Deposition (CVD). PVD and CVD are at present not used on an industrial scale for coating strip material, but in view of the current developments in this field it is to be expected that these deposition methods can be used in the foreseeable future for coating a

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substrate in a cheaper way than cladding the substrate. PVD and CVD will then be a good alternative for plating to deposit nickel.

Preferably the plate consists of a core layer of steel, a copper or nickel clad layer on one surface of the core layer and a deposited nickel layer on the other surface of the core layer. No intermediate layers are present according to this preferred embodiment and the amount of deposited metals used is as low as possible.

According to another preferred embodiment, the plate consists of a core layer of steel, a deposited nickel layer on both surfaces of the core layer and a copper or nickel clad top layer on one of the nickel layers. Here a nickel layer is deposited on both surfaces of the core layer of steel.

In this case it is preferred if the nickel layer between the core layer of steel and the copper or nickel clad top layer is thinner than the deposited nickel top layer. When plating one side of a plate with nickel, the other side is also plated with a much thinner layer of nickel if no special measures are taken. The copper or nickel clad layer is present on this thin plated nickel layer.

The core layer of the plate can of course be made of stainless steel, as is the case in the known stainless steel copper and/or nickel clad product used for housings and lids for button cell batteries. However, according to a preferred embodiment the core layer consists of mild steel, preferably of deep drawing quality. Mild steel can be used because the risk that the lid will corrode is almost absent, since the nickel layer provides a good enough corrosion protection of the outer surface of the lid and the cutting edge of the lid is encapsulated in a plastic sealing ring between the drawn sidewall of the lid and the inside of the sidewall of the can of the button cell battery. Stainless steel is more expensive than mild steel, so the use of mild steel results in a mayor cost reduction. Mild steel has mechanical properties that are different from the mechanical properties of stainless steel, but that are good enough for housings and lids of button cells. To produce housings and lids with the form of a cup, the steel preferably has a deep drawing quality.

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The plate could be produced with a thickness between 0.1 and 0.5 mm, preferably between 0.1 and 0.2 mm. This preferred thickness enhances the mechanical properties of the housings and lids made of this plate.

According to a second aspect of the invention there is provided a housing and a lid for a button cell battery fabricated from a plate according to the first aspect of the invention. The housings and lids for button cell batteries fabricated from this plate according to the invention are cheaper than the present housings and lids.

According to a third aspect of the invention there is provided a process for manufacturing a plate according to the first aspect of the invention, the process comprising the steps:

- providing a hot rolled mild steel plate having a thickness between 0.7 and 5 mm, preferably 2.1 mm and
- rolling the steel plate to a thickness of preferably 1.0 mm;
- 15 - or;
- providing a cold rolled mild steel plate having a preferred thickness of 1.0 mm;
- depositing a nickel layer of 5 to 20 μm , preferably 10 μm thick on one side of the steel plate and optionally a nickel layer having a maximum thickness of 3 μm on the other side;
- 20 - cladding a copper or nickel layer of 1 to 20 %, preferably 5 to 10 %, of the thickness of the steel plate on the other side of the steel plate;
- rolling and annealing the steel plate to a thickness of 0.1 and 0.5 mm, preferably 0.1 and 0.2 mm.
- 25

This process provides a plate for producing housings and/or lids for button cells that is cheaper than the known stainless steel copper and/or nickel clad product, due to the depositing of the nickel layer instead of the cladding of the nickel layer for the outside of the housings and lids as is necessary for the known stainless steel product.

30

To also deposit a nickel layer having a maximum thickness of 3 μm on the other side of the steel plate is advantageous when the nickel is deposited by plating, because the plating process of nickel on one side of

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the steel plate is easier when at the same time a thin nickel plated layer is formed on the other side of the steel plate.

According to one embodiment of the process, the mild steel plate having a thickness of preferably 1.0 mm is annealed before the nickel layer is deposited.

According to a preferred embodiment, the mild steel plate with the deposited nickel layer is diffusion annealed after the nickel layer has been deposited. This has the advantage that during annealing also diffusion takes place. This results in a stronger adhesion between the nickel and the steel plate, and in a ductile, homogeneous and highly corrosion resistant dense nickel iron alloy layer.

Preferably, the mild steel plate is annealed before the plate is rolled to its final thickness of 0.1 to 0.5 mm, preferably 0.1 to 0.2 mm. This results in an advantageous performance of the mild steel plate by generating the nickel iron containing diffusion layer.

According to one preferred embodiment of the method, the nickel is deposited using Physical Vapour Deposition (PVD) or Chemical Vapour Deposition (CVD). The advantages of the use of PVD and CVD have been elucidated above.

According to another preferred embodiment of the method, the nickel is deposited by plating, preferably electrolytic strip plating. The advantages of plating have been elucidated above.

The invention will be elucidated using the description of a preferred plate and a preferred process for manufacturing such a plate.

According to a preferred embodiment, the plate according to the invention consists of three layers. In the middle of the plate a core layer of mild steel is present. This mild steel is of deep drawing quality. The thickness of the core layer is preferably 0.1 to 0.2 mm. At one side of the core layer is present a deposited layer of nickel having a thickness of approximately 1 to 2 μm . At the other side of the core layer is present a clad copper or nickel layer having a thickness of approximately 5 to 30 μm . The total thickness of the plate is preferably 0.1 to 0.2 mm.

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This plate can be directly used to fabricate housings (also called cans or cases) and/or lids for button cell batteries, by punching and drawing.

According to another preferred embodiment in addition to the three above mentioned layers, a deposited nickel layer is present between the clad copper or nickel layer and the core layer. This nickel layer has a thickness of 0.1 to 3 μm , preferably 1 to 2 μm . This nickel layer has no consequence for the functionality of the housings and/or lids fabricated from this plate, in view of the presence of the copper or nickel clad top layer.

According to a preferred process for the manufacturing of the above plate, the following process steps are taken:

- providing a hot rolled mild steel plate of deep drawing quality having a thickness of 0.7 to 5 mm, preferably 2.1 mm, which thickness is commercially available and
- pickling the hot rolled steel plate and
- cold rolling the steel plate to a thickness of approximately 1.0 mm;
- or:
- providing a cold rolled mild steel plate in deep drawing quality having a preferred thickness of 1.0 mm;
- either: first annealing the steel plate and subsequently nickel plating a layer of approximately 10 μm on one side of the steel plate,
- or: first nickel plating a layer of approximately 10 μm on one side of the steel plate and subsequently diffusion annealing the plate;
- cladding a copper or nickel layer of 1 to 20 %, preferably 5 to 10 %, of the thickness of the plate on the other side of the steel plate and rolling the plate to a thickness of approximately 0.40 mm;
- rolling the plate to a thickness of preferably 0.1 to 0.2 mm by using intermediate annealing;

Most of these steps are known from the usual process for manufacturing stainless steel copper and/or nickel clad products consisting of a core layer of stainless steel with a clad nickel top layer and a clad copper or nickel top layer. However, the use of plating to apply the nickel top layer for the outside of housings and/or lids and the use of mild steel are not known. Both these

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measures provide a substantial reduction in the cost price of the plate manufactured according to the present invention.

Though the process described above uses plating to deposit the nickel layer, it is also possible to use other depositing methods, such as PVD and
5 CVD.

According to another preferred process, when plating the nickel layer on one side of the steel core layer, on the other side of the core layer a nickel layer is plated as well. This plated nickel layer of approximately 0.1 to 3 μm thick is deposited automatically during the plating of the nickel layer of
10 10 μm , unless special measures are taken to prevent the deposit of this thin nickel layer. It could therefore be advantageous to have this thin nickel layer deposited, instead of spending the money to prevent this deposit.

Instead of the above used mild steel for the core layer, it is of course possible to use stainless steel, as in the known stainless steel clad products.
15 However, this is more expensive. The use of normal mild steel is a good substitute for stainless steel; the mechanical properties of such mild steels are good enough for the housings and/or lids for button cell batteries to be produced.

The plate producing housings and/or lids for button cell batteries
20 according to the invention is preferably produced as strip. Strip plating provides further cost reduction potential in comparison with piece plating. This is also the case for cladding of strip. For this invention, where the word 'plate' has been used, also the word 'strip' can be read.

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CLAIMS

1. Plate for producing housings and/or lids for button cell batteries,
5 comprising a core layer of steel, a copper or nickel clad top layer at one side of the core layer and a nickel top layer at the other side of the core layer, characterized in that the nickel top layer has been applied by depositing the nickel and in that the core layer of steel has a thickness from 0.10 to 0.5 mm.
- 10 2. Plate according to claim 1, wherein the nickel layer has been applied by plating, preferably electrolytic strip plating.
3. Plate according to claim 1, wherein the nickel layer has been applied by
15 Physical Vapour Deposition (PVD) or by Chemical Vapour Deposition (CVD).
4. Plate according to claim 1, 2 or 3, wherein the plate consists of a core
20 layer of steel, a copper or nickel clad layer on one surface of the core layer and a deposited nickel layer on the other surface of the core layer.
5. Plate according to claim 1, 2 or 3, wherein the plate consists of a core
25 layer of steel, a deposited nickel layer on both surfaces of the core layer and a copper or nickel clad top layer on one of the nickel layers.
6. Plate according to claim 5, wherein the deposited nickel layer between
the core layer of steel and the copper or nickel clad top layer is thinner
than the deposited nickel top layer.
- 30 7. Plate according to any one of the preceding claims, wherein the core layer consists of mild steel, preferably of deep drawing quality.

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8. Plate according to any one of the preceding claims, wherein the plate has a thickness between 0.1 and 0.5 mm, preferably between 0.1 and 0.2 mm.
- 5 9 Housing for a button cell battery fabricated from a plate according to any one of the claims 1 – 8.
- 10 10. Lid for a button cell battery fabricated from a plate according to any one of the claims 1 - 8.
11. Process for manufacturing of a plate according to any one of the claims 1 – 8, the process comprising the steps:
- providing a hot rolled mild steel plate having a thickness between 0.7 and 5 mm, preferably 2.1 mm and
 - 15 - rolling the steel plate to a thickness of preferably 1.0 mm;
 - or;
 - providing a cold rolled mild steel plate having a preferred thickness of 1.0 mm;
 - 20 - depositing a nickel layer of 5 to 20 μm , preferably 10 μm thick on one side of the steel plate and optionally a nickel layer having a maximum thickness of 3 μm on the other side;
 - cladding a copper or nickel layer of 1 to 20 %, preferably 5 to 10 %, of the thickness of the steel plate on the other side of the steel plate;
 - 25 - rolling and annealing of the steel plate to a thickness of 0.1 and 0.5 mm, preferably 0.1 and 0.2 mm.
12. Process according to claim 11, wherein the mild steel plate having a thickness of preferably 1.0 mm is annealed before the nickel layer is deposited.
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13. Process according to claim 11, wherein the mild steel plate with the deposited nickel layer is diffusion annealed after the nickel layer has been deposited.
- 5 14. Process according to claim 11, 12 or 13, wherein the mild steel plate is annealed before the plate is rolled to its final thickness of 0.1 to 0.5 mm, preferably 0.1 to 0.2 mm.
- 10 15. Process according to any one of claims 11 - 14, wherein the nickel is deposited using Physical Vapour Deposition (PVD) or Chemical Vapour Deposition (CVD).
16. Process according to any one of claims 11 - 14, wherein the nickel is deposited by plating, preferably electrolytic strip plating.

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(54) Electrochemical cells and components thereof

(57) An electrochemical cell (10), typically an air depolarized cell of the button-type has non-reactive elements significantly thinner than corresponding non-reactive elements of prior art cells. Such elements are thinner thanks to improved structures of such elements. Among these elements is an anode can (24) which is made from a metal strip structure having a high steel content. Another element is the cathode can (40) which has a modified temper and improved relative stiffness

and rigidity, while retaining sufficient ductility to tolerate forming the cathode can. By so reducing the thicknesses of non-reactive elements of the cell (10), and thus the volume occupied by such non-reactive elements, the fraction of the volume of the cell (10) devoted to holding electrochemically reactive anode material (26) therein is increased, yielding a corresponding increase in the milliampere hour capacity of the cell.

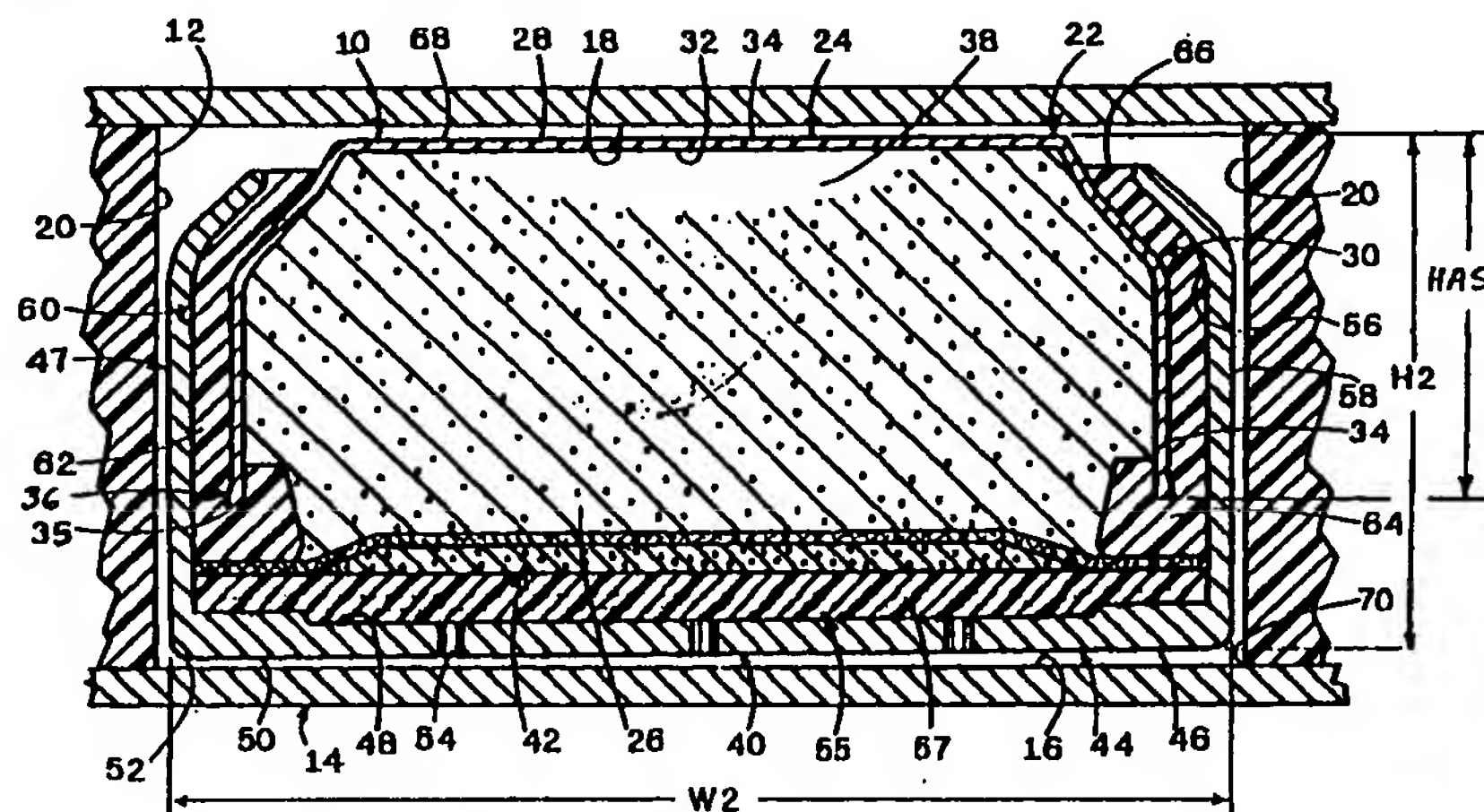


FIG. 2

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Description

[0001] This invention relates to electrochemical cells, especially alkaline electrochemical cells. Typical cells of the invention have air cathodes, and are commonly known as air depolarized cells. More particularly, this invention relates to the structural components from which the cell is assembled, and to the overall structure of the cell itself, and generally addresses the efficient use of the three-dimensional volume available for use by such cells in electrical appliances. The invention addresses, specifically, efficient use of non-reactive e.g. structural materials in preserving as much of the three-dimensional volume as possible for occupation by the electrochemically reactive materials used by the cell for generating electrical energy. Such efficient use of appliance volume provides an increase in the fraction of the overall volume of the cell which can be allocated to/occupied by the electrochemically reactive materials.

[0002] The growth in use of small electrically-powered devices has increased the demand for very small air depolarized electrochemical cells. Air depolarized cells have gained significant popularity because only the anode reaction material need be packaged in the cell. In combination, the cathode reaction material is oxygen, which is drawn from the surrounding environment.

[0003] Such small cells are usually disc-like or pellet-like in appearance, and are about the size of garment buttons. These cells generally have diameters ranging from less than 6.4 millimeters to about 25 millimeters, and heights ranging from less than 3.8 millimeters up to about 15 millimeters. The small size and the limited amount of electrochemically reactive material which can be contained in such small metal-air cells result in a need for improving the efficiency and completeness of the electrochemical reaction, which are used in such cells for generating electrical energy.

[0004] Air depolarized cells, having aqueous alkaline electrolyte, take in atmospheric oxygen, and convert the oxygen to hydroxyl ions in the air cathode. The hydroxyl ions then migrate to the anode, where they cause the electroactive anode material to oxidize. Typically active anode material in such cells comprises zinc.

[0005] More particularly, the desired reaction in the air cathode of an air depolarized cell involves the reduction of oxygen, the consumption of electrons, and the production of hydroxyl ions. The hydroxyl ions migrate through the electrolyte toward the anode, where oxidation occurs, forming oxides such as zinc oxide.

[0006] In air depolarized cells, air enters the cell through one or more ports in the bottom of the cathode can. The port or ports extend through the bottom of the cathode can, and may be immediately adjacent the cathode assembly, or may be separated from the cathode assembly by an air reservoir or an air diffusion member, or both.

[0007] In any of such arrangements, the port facilitates the movement of air through the bottom of the cathode can and to the cathode assembly. At the cathode assembly, the oxygen in the air reacts with water as a chemically reactive participant in the electrochemical reaction of the cell, and thereby forms the hydroxyl ions.

[0008] Since the overall electrochemical capacity of any electrochemical cell is to some extent determined by the quantity of electrochemically reactive materials which can be loaded into the cell, it is important to maximize, in the cell, the size of the cavity which is devoted to containing the electrochemically reactive materials. In the case of an air depolarized cell, contained reactive material is limited to the anode material. The improvements recited herein could, however, be applied to a variety of other electrochemical cells, and need not be, indeed are not, limited to air depolarized cells.

[0009] In general, the size of any given cell is limited by the inside dimensions of the space provided in the article, namely the appliance, in which the cell will operate. For example, the size of a hearing aid cell is limited to the internal dimensions of the space provided for the cell, in the hearing aid appliance. The internal dimensions of the space are determined by the hearing aid manufacturer, not the power cell manufacturer.

[0010] Thus, any given appliance includes a limited amount of gross space/volume allotted to occupancy by the electrochemical cell which powers the appliance. That gross space may ultimately be divided according to four functions, all competing for portions of the gross space. A first and minimal portion of the space is used to provide clearance between those interior boundaries of the appliance which boundaries define the space, and the exterior elements of the electrochemical cell.

[0011] A second portion of the space is occupied by the structural and otherwise non-reactive elements of the electrochemical cell.

[0012] The third portion of the space is allocated for occupation by the electrochemically reactive material in the electrochemical cell, and, in an air depolarized cell, especially the anode material.

[0013] Finally, a fourth portion of the space, if used, can sometimes be described as "wasted" space, because it serves none of the above first through third functions. Such "wasted" space is typically found outside the cell, e.g. at corner locations, where the corner of the cell is less "square" than is structurally feasible, thereby wasting volume that potentially might be occupied, either directly or indirectly, by electrochemically reactive material. Such "wasted" space might also be considered to be included in the space allocated to "clearance" because such space is typically located outside the cell.

[0014] Any increase in the third portion of the space, namely the cavity which is allocated to the anode material, is necessarily gained at the expense of one or more of the other three portions of the fixed volume allocated for occupation

by the cell, namely the first clearance portion, the second portion devoted to the non-reactive elements of the cell, or any fourth waste portion. Thus, it is important to identify the first, second, and fourth portions of the overall space, and, where possible, to reduce the amount of the space devoted to such uses. To the extent such uses can be reduced, the space so recovered can, in general, be allocated for use to hold additional amounts of electrochemically reactive anode material, thereby increasing the potential overall capacity of the cell to generate electrical energy within the limited amount of gross space/volume provided, in the appliance, for occupation by the cell.

[0015] Of the first, second, and fourth portions of the cell, the first portion, devoted to clearance, appears to hold the least potential for providing much, if any, significant opportunities for reduction in volume, and the total volume of the "clearance" space is typically relatively small. Namely, overall cell height and width dimensions are specified by the International Electrochemical Commission (IEC). Regarding the fourth portion, while some cell manufacturers may employ designs which utilize readily definable wasted space on the outside of the cell, especially at lower corners of the cell, other manufacturers appear to more fully utilize the allocated space. Accordingly, while some small amount of volume may be recovered from "wasted" space, such as by reducing the "clearance" space, applicant has concluded that only minimal potential exists for recovering such fourth portion "wasted" space.

[0016] Rather, applicant believes that the greatest potential for recovering space for use in holding anode material, and thus to increase "volume efficiency" of the cell, lies in the second portion of the cell, namely the structural and otherwise non-reactive elements of the cell. These elements generally comprise the cathode can, the anode can, the seal, and the cathode assembly, these typically representing all of the major structural elements of the cell except for the reactive anode material. Thus, to get more space for holding the reactive anode material, that space must generally be taken away from the anode can, the cathode can, the cathode assembly, or the seal, or some combination of these.

[0017] It is an object of this invention to provide electrochemical cells having increased fractions of the cell-receiving space of the appliance devoted to containing electrochemically reactive anode material.

[0018] It is another object to provide air depolarized electrochemical cells wherein the thicknesses of one or more of the anode can, the cathode can, the cathode assembly, or the seal have been reduced to thicknesses never before achieved for an electrochemical cell.

[0019] It is still another object of the invention to provide such cells wherein the structural integrity of the cell, to abuse from forces outside the cell, is maintained.

[0020] Yet another object is to provide improved anode cans, especially with reduced wall thicknesses.

[0021] Still another object is to provide improved cathode cans, especially with reduced wall thickness.

[0022] Some of the objects are obtained in an electrochemical cell. The cell comprises an anode, including an anode can and an anode cavity disposed primarily in the anode can, and electrochemically reactive anode material: a cathode, including a cathode can, and a cathode assembly in the cathode can; and a seal between the anode can and the cathode can. The anode and cathode are joined together, with the seal therebetween and, in combination, define a top and a bottom of the cell and a height therebetween. Side walls define a diameter of the electrochemical cell. The height and the diameter, in combination, define an overall volume of the cell of typically between .06 cm³ and .60 cm³, and ratio of overall height to maximum diameter of about .25/1 to about .80/1, preferably about .44/1 to about .68/1. The anode cavity comprises a measurable fraction of the overall volume of the cell. In cells of the invention, the fraction is preferably at least as great as the value represented by the expression

$0.65 + [\text{Log}_{10}(\text{Overall Volume})] \cdot 0.20$. A variety of other expressions represent varying levels of development of the invention. Thus, the fraction may be at least as great as the value represented by the expression

$$0.69 + [\text{Log}_{10}(\text{Overall volume})] \cdot 0.22.$$

[0023] In preferred embodiments, the fraction is represented by a range, the lower end of the range being represented by the expression

$$0.65 + [\text{Log}_{10}(\text{Overall Volume})] \cdot 0.20,$$

and the approximate upper end of the range being represented by the expression

$$0.77 + [\text{Log}_{10}(\text{Overall Volume})] \cdot 0.20.$$

In a more preferred range, the value is represented by the expression

$$0.65 + [\text{Log}_{10}(\text{Overall Volume})] \cdot 0.20,$$

up to the value represented by the expression

$$0.80 + [\text{Log}_{10}(\text{Overall Volume})] * 0.281,$$

more preferably the value being represented by the expression

$$0.65 + [\text{Log}_{10}(\text{Overall Volume})] * 0.20,$$

up to the value represented by the expression

$$0.77 + [\text{Log}_{10}(\text{Overall Volume})] * 0.28,$$

and still more preferably the value being represented by the expression

$$0.69 + [\text{Log}_{10}(\text{Overall Volume})] * 0.22,$$

up to the value represented by the expression

$$0.77 + [\text{Log}_{10}(\text{Overall Volume})] * 0.20.$$

The value of the fraction is well represented by the expression

$$0.69 + [\text{Log}_{10}(\text{Overall Volume})] * 0.22.$$

[0024] For example, where the volume of the cell is .06 cm³ to .12 cm³, the ratio of the volume of the anode cavity to the overall volume of the cell, namely the anode cavity fraction, is at least 0.43/1. Where the cell volume is .12 cm³ to .20 cm³, the anode cavity fraction is at least .46/1. Where the cell volume is .20 cm³ to .30 cm³, the anode cavity fraction is at least .53/1. Where the cell volume is .50 cm³ to .60 cm³, the anode cavity fraction is at least .59/1.

[0025] Other objects of the invention are achieved in a novel anode can for use in an electrochemical cell. The novel anode can has a top wall, and a circumferential side wall extending downwardly from the top wall, the anode can having an outer surface disposed outwardly on the top wall and outwardly on the side wall, and an inner surface disposed inwardly on the top wall and inwardly on the side wall. The novel anode can comprises a structure having a first layer and a second layer, and a third layer disposed between the first and second layers.

[0026] The first layer preferably comprises nickel. The second layer preferably comprises copper. The third layer preferably comprises stainless steel.

[0027] The third layer comprises about 79 percent by volume to about 91 percent by volume, preferably about 80 percent by volume to about 91 percent by volume, more preferably about 83 percent by volume to about 91 percent by volume, still more preferably about 87 percent by volume to about 91 percent by volume.

[0028] The first and second layers, in combination, comprise about 9 percent by volume to about 21 percent by volume, preferably about 9 percent by volume to about 20 percent by volume, more preferably about 9 percent by volume to about 17 percent by volume, still more preferably about 9 percent by volume to about 13 percent by volume, of the anode can.

[0029] In some embodiments, it is preferred that the first layer comprise about 2 percent by volume to about 7 percent by volume of the anode can, and that the second layer comprise about 7 percent by volume to about 16 percent by volume of the anode can.

[0030] In yet other embodiments, it is preferred that the first layer comprise about 2 percent by volume to about 6 percent by volume of the anode can, and that the second layer comprise about 7 percent by volume to about 11 percent by volume of the anode can.

[0031] The thickness of the novel anode cans of the invention, between the inner and outer surfaces, whether of the top wall, of the side wall, or both, is from about .075 millimeter up to less than .11 millimeter, preferably from about .09 millimeter up to about .11 millimeter, more preferably from about .10 millimeter up to less than .11 millimeter.

[0032] The invention comprehends electrochemical cells made with anode cans of the invention. Such cell includes a cathode can joined with the anode can, and a seal between the anode can and the cathode can.

[0033] Still other objects are achieved in an electrochemical cell having an anode as disclosed herein, a cathode, an electrolyte, and a barrier between the anode and the cathode. The cathode comprises a cathode can joined with the anode can, the overall volume of the cell being between about .06 cm³ and about .60 cm³. The cathode can typically comprises a three-layer structure having a first layer of cold rolled steel, between second and third layers of nickel. The cathode can has a thickness between the inner and outer surfaces thereof, from about .075 millimeter up to less than .14 millimeter, preferably from about .075 millimeter up to about .13 millimeter, more preferably from about .09 millimeter up to less than .10 millimeter.

[0034] Additional layers can be used as desired either outside one or both of the second and third layers, or between the first layer and one or both of the second and third layers.

[0035] Embodiments of the present invention will now be described by way of example in the following description, which is to be read in conjunction with the accompanying drawings, in which:

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FIGURE 1 shows a cross-section of a prior art air depolarized electrochemical cell in an appliance, inside the space allocated for the cell.

FIGURE 2 shows a cross-section of an air depolarized electrochemical cell of the invention in a corresponding appliance as in FIGURE 1, also inside the space allocated for the cell.

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FIGURE 3 shows a pictorial view of a cathode assembly used in cells of the invention.

FIGURE 4 shows a cross-section of the cathode assembly, taken at 4-4 of FIGURE 3.

FIGURE 5 illustrates the die arrangement, and the final stage of the method used to bring together the anode, the cathode, and the seal, to thereby close and crimp the respective elements in assembly of the cell.

FIGURE 6 shows a fragmentary cross-section of metal strip used to make cathode cans of the invention.

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FIGURE 7 shows a fragmentary cross-section of metal strip used to make anode cans of the invention.

FIGURE 8 shows a split-half, side-by-side cross-section comparison of two halves of an air depolarized cell, illustrating the volume gains achieved using the invention.

FIGURE 9 is a graph illustrating Volume Efficiencies of cells of the invention, compared with conventional cells.

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[0036] Referring now by characters of reference to the drawings, a comparison of FIGURES 1 and 2 illustrates the general concept of the invention. Referring first to FIGURE 2, the cell 10 is disposed inside the space 12 allocated for occupation by the cell, in an appliance 14. As illustrated in FIGURE 2, space 12 is generally bounded by a bottom wall 16 of the appliance, a top wall 18 of the appliance, and side walls 20 of the appliance.

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[0037] Referring, now, specifically to cell 10 illustrated in FIGURE 2, negative electrode 22, also referred to as anode 22, includes an anode can 24 and electrochemically reactive anode material 26 contained therein. Anode can 24 has a top wall 28, and circumferential side wall 30 depending downwardly from top wall 28. Top wall 28 and side wall 30 have, in combination, an inner surface 32 and an outer surface 34. Side wall 30 has a height "HAS" shown in FIGURE 2, generally corresponding to the overall height of the anode can, and terminates in a distal edge 35 at circumferential can foot 36.

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[0038] Positive electrode 40, also referred to as cathode 40, includes a cathode assembly 42, contained within cathode can 44. Cathode can 44 has a bottom wall 46, and a circumferential upstanding side wall 47 extending upwardly from bottom wall 46. Bottom wall 46 has a generally flat inner surface 48, which may incorporate a step recess therein, a generally flat outer surface 50, and an outer perimeter 52 defined on flat outer surface 50. A plurality of air ports 54 extend through bottom wall 46 of the cathode can, providing avenues for transport of oxygen into the cell adjacent cathode assembly 42. An air reservoir 55 spaces cathode assembly 42 from bottom wall 46 and the corresponding ports 54. A porous diffusion layer 57 fills air reservoir 55. Side wall 47 of the cathode can has an inner surface 56 and an outer surface 58.

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[0039] Anode 22 is electrically insulated from cathode 40 by a seal 60. Seal 60 includes a circumferential side wall 62 disposed between upstanding side wall 47 of the cathode can and downwardly-depending side wall 30 of the anode can, a seal foot 64 disposed generally between foot 36 of the anode can and cathode assembly 42, and a seal top 66 where side wall 62 of seal 60 extends from between side walls 30 and 47 adjacent the top of the cell.

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[0040] Top wall 28, side wall 30, cathode assembly 42, and seal foot 64, in combination, generally define anode cavity 38 primarily within the anode can, which anode cavity 38 contains the anode material 26.

[0041] Outer surface 68 of cell 10 is thus defined by portions of the outer surface 34 of the top of the anode can, outer surface 58 of side wall 47 of the cathode can, outer surface 50 of the bottom of the cathode can, and top 66 of seal 60.

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[0042] In general, this invention addresses the materials and structures which affect the degree of efficiency with which cell 10 fills space 12 with electrochemically reactive material. Accordingly, the invention addresses materials, structures, and methods for improving the efficiency with which cell 10 fills space 12 with electrochemically reactive material. To the extent feasible within other constraints on making and using the cell, the cell should have a flat top wall and a flat bottom wall. Side wall 47 should meet bottom wall 46 at a generally perpendicular angle. The top corner of the cell, adjacent top 66 of seal 62 should be as close as possible to the corresponding upper corner of space 12.

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[0043] Returning again to the prior art, the cell of FIGURE 1 is derived from United States Patent Re. 31.143. A comparison of the cell of the prior art shown in FIGURE 1 to the cell 10 of the invention illustrated in FIGURE 2 suggests the significance of the configuration of the outer walls of the cell to the efficiency with which the cell fills the space 12.

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First addressing the "clearance" portion of space 12, the values for the maximum diameter "W1" of the prior art cell in FIGURE 1 and the height "H1" of the cell are less than the respective values for the maximum diameter "W2" of the cell of the invention in FIGURE 2 and the height "H2" of the cell of the invention. The affect of such difference in the absolute values is that the volume defined between the outer surface of the cathode can of the prior art cell of FIGURE 1 and the

side walls 20 of the space 12 is greater than the volume defined between the outer surface 58 of the cathode can of the invention and the side walls 20 of the space 12. Accordingly, the cell 10 of the invention, as can be seen visually from the comparison of FIGURES 1 and 2, illustrates better use of the first "clearance" portion of space 12.

5 [0044] Further examination of FIGURE 1 illustrates the principle of the fourth portion of space 12, namely the "wasted" portion of the space. As seen there, the bottom wall of the cathode can is convex, whereby the outer bottom corners of the space are not occupied by the cell but are, rather, vacant and "wasted" as suggested by the designation "WA" therein. The areas designated "WA" also illustrate a second indicator of waste in the in-cut corners "IC" between the convex portion of the bottom wall and the downwardly inclined portion of the cell which is disposed outwardly thereof but inwardly of the upstanding side wall of the cathode can. The cell 10 of the invention, on the other hand, efficiently
10 uses the outer bottom corners 70 of space 12, as illustrated in FIGURE 2.

[0045] Having thus described conceptually the desire to efficiently fill as much as possible of space 12 with cell 10, methods of so filling the space, and of maximizing the fraction of the volume of the cell which is occupied by electrochemically reactive material, will be discussed following.

15 The Seal

[0046] Seal 60 performs at least two primary functions. First, the seal serves as a closure for the cell, to prevent anode material and/or electrolyte from leaking from the cell between outer surface 34 of side wall 30 of the anode can and inner surface 56 of side wall 47 of the cathode can. Thus, the seal must possess adequate liquid sealing properties to
20 prevent such leakage. Generally, such properties are available in a variety of resiliently deformable thermoplastic polymeric materials.

[0047] Second, the seal provides electrical insulation, preventing all effective direct electrical contact between anode can 24 and cathode can 44. Accordingly, side wall 62 of the seal must circumscribe, and provide electrical insulation properties about, the entirety of the circumference of the cell between outer surface 34 and inner surface 56, generally
25 from the top of side wall 47 to the bottom of side wall 30. Similarly, foot 64 of the seal must circumscribe, and provide electrical insulation properties about, the entirety of the circumference of the cell between foot 36 of side wall 30, the lower portion of side wall 47, and the outer perimeter portion of cathode assembly 42. The combination of good liquid sealing properties and good electrical insulation properties can typically be achieved by molding known battery-grade nylon polymeric material in the desired configuration.

30 [0048] To meet the electrical insulation requirements, the seal must have good dielectric insulation properties, must have at least a minimum thickness about side wall 62, and must be free of any pinholes or other imperfections that might permit transmission of electric current between side walls 30 and 47. Thickness for seal side wall 62 of about .20 to about .25 millimeter is common in conventional electrochemical cells. Thickness as low as .16 millimeter is known.

[0049] In the invention, seals thinner than .16 millimeter, as thin as .10 millimeter, made from the same resiliently
35 deformable thermoplastic nylon material as the thicker .16 millimeter seals, surprisingly exhibit acceptable properties, both liquid seal properties and electrical insulation properties. Depending on the structure of the cell to which the seal is to be applied, intermediate thicknesses such as e.g. .15 millimeter, .14 millimeter, .13 millimeter, or the like, may be selected for some cells. However, where cell volume efficiency is a driving consideration, preferred thicknesses are less, for example .12 millimeter or .11 millimeter to as thin as .10 millimeter. Thus, the range of thicknesses for seals 60
40 preferred for use in cells 10 of the invention has a lower end of about .10 millimeter and an upper end of about .15 millimeter. All thicknesses between the lower and upper ends of the range are operable, and thus are included for use in the cells of the invention. Suitable such nylon seals are available from Suratco Products Company, Poynette, Wisconsin USA.

45 The Cathode Assembly

[0050] FIGURES 3 and 4 show respective perspective and cross-section views of the cathode assembly 42 used in cells representative of the present invention. Active layer 72 or one cathode assembly is interposed between barrier layer 74 and air diffusion layer 57. Active layer 72 ranges preferably between about .05 millimeter and about 1.3 millimeter thick, and facilitates the reaction between the hydroxyl in the aqueous alkaline electrolyte and the cathodic oxygen
50 of the air. Barrier layer 74 is a microporous plastic membrane about .02 millimeter thick, typically polypropylene, having the primary function of preventing anodic zinc particles from coming into physical contact with the remaining elements of the cathode assembly 42. Barrier layer 74 however, does permit passage of hydroxyl ions and water therethrough.

[0051] Air diffusion layer 57 is preferably a micro-porous hydrophobic polymeric material such as a polytetrafluoroethylene (PTFE) membrane about .02 to about .05 millimeter thick, which permits passage of air therethrough and which is generally impervious to battery electrolyte, namely potassium hydroxide and other known electrolytes.

[0052] Referring to FIGURE 4, active layer 72 further contains connecting substratum capable of being connected, as a current collector, to electrical circuitry, namely conductive woven nickel wire layer 76. Carbon, indicated at 78, pref-

erably forms a matrix surrounding conductive layer 76 of nickel wire. Nickel is preferred for layer 76 because nickel exhibits little or no corrosion in the alkaline environment of a zinc-air cell, and also because nickel is an excellent electrical conductor.

[0053] In addressing a primary objective of the invention, the thickness of the cathode assembly including barrier layer 74 and diffusion layer 57, should desirably be as small as possible. A cathode assembly preferred for use in electrochemical cells of the invention may be made as follows. Place e.g. 1000 milliliters of distilled water in a non-reactive container, and add 19 grams of KMnO_4 thereto. Mix this solution for ten minutes. Then slowly add 204 grams of PWA activated carbon having the appropriate particle sizes to the central mix vortex.

[0054] PWA activated carbon has the following characteristics: surface area between about 1000 and $1.150 \text{ m}^2/\text{g}$., apparent density of about 0.51 g/cc ., real density of about 2.1 g/cc ., pore volume of about 0.90 g/cc ., specific heat at 100 degrees C, of about 0.25, and about 65% by weight to about 75% by weight of such material will pass through a wet -325 U.S. mesh screen.

[0055] After 10 minutes of mixing, slowly and uniformly, and without interruption, add 51 grams of Teflon[®] T-30 dispersant to the edge of the mix vortex, and continue mixing for yet another ten minutes at the speed required to maintain a vortex in the mix after the Teflon dispersant is added. Filter the resulting solution through Whatman #1 filter paper, and heat to between 100 degrees C, and 140 degrees C., in a mechanical convection drying oven for at least 16 hours, or until dry, to yield a suitable cake of cathode material.

[0056] Combine the resulting cathode material with Black Pearls 2000 carbon black and mix for 30 minutes, or until the mix becomes free flowing. Roll the resulting cathode mix between conventional stainless steel roller mills to obtain the active layer 72. Further details for making such preferred cathode assemblies 42 for use in cells 10 of the invention, including methods for incorporating conductive layer 76 of nickel wire into the cathode assembly, are disclosed in United States Patent 5,308,711, herein incorporated by reference in its entirety.

The Cathode Can

[0057] FIGURE 5 illustrates the die arrangement, and the process of bringing together the anode and the seal, received inside cathode can 44, to close the cell and crimp the distal edges of the cathode side wall about the anode. Referring now specifically to FIGURE 5, a closing punch 100 exerts an upwardly directed force 102, indicated by the double headed arrows, against bottom wall 46 of cathode can 44. An opposing ejector bunch 104 exerts an opposing downwardly directed force 106 of lesser magnitude, indicated by the double headed arrows, against top wall 28 of anode can 24. Split closing die 108 generally surrounds the cavity in which the cell is closed and crimped.

[0058] As closing punch 100 exerts the upwardly-directed force 102 indicated by arrows, thus urging the cathode can against the anode can and the seal, the cathode can is moved into the closing die 108 and against the transverse crimping lands 110 of the die. At the same time, ejector punch 104 exerts its downwardly-directed opposing force 106 against the anode can. In order for the closing punch 100 to force the cathode can closed, it must exert sufficient force to form the crimp on the distal edges 112 of the side wall 47, the crimp at distal edges 112 exerting closing force through seal 60 and against side wall 30 of the anode can, thus gripping anode can 24 and seal 60 in closure of the cell ; as well as sufficient force to overcome the resistance of the downwardly-directed opposing force 104 on the anode can.

[0059] Force 104 on the anode can has at least two purposes. First, force 104 helps stabilize the anode can while the cell is being closed. Second, force 104 is exerted through seal 60 against inner surface 48 of bottom wall 46 of the cathode can, and thus generally opposes any bending moment which may be imposed on bottom wall 46 of the cathode can, thus tending to reduce any risk that bottom wall 46 may be deformed as the cell is being closed.

[0060] The amount of bending moment exerted on bottom wall 46 can be controlled by properly structuring the bottom corner of cathode can 14, where bottom wall 46 meets side wall 47. Namely, by fabricating can 44 with a sharp corner as taught in USA Patent 5,662,717 issued 2 September, 1997, to Burns, the bending moment imposed on bottom wall 46 is controlled such that a Temper softer than 3.5 can be employed.

[0061] The cathode can has a first thickness between its inner and outer surfaces 56, 58 at side wall 47, and a second thickness between its inner and outer surfaces 48, 50 at bottom wall 46, at least one of which thicknesses can be less in the invention, compared to prior art cells, by making the cathode can according to improved can fabrication processes taught herein. For making conventional button-type cells, it is known to use a three-layer metal strip 114, illustrated in FIGURE 6, including a core layer 116 of AISI 1008. Aluminum Killed, Battery Grade cold rolled steel, plated on opposing surfaces with layers 118 of nickel, each of the layers 118 being about .00165 mm to about .00215 mm thick. The plated three-layer structure 114 is diffusion annealed such that the nickel layers 118 are diffusion bonded to the core layer 116. The diffusion annealed three-layer strip 114 is then temper rolled to specified thickness. Conventionally-known such three layer structures have limited ability to withstand the closing forces 102, 106 as the thickness of the three-layer metal strip 114 is reduced. In the invention, the thickness of the metal strip 114 can be further reduced where the physical characteristics of metal strip 114 are properly controlled. Table 1 sets forth comparable properties for a metal strip of the invention, as Invention Example #1, and Comparative Example #1 for a prior art metal strip.

[0062] As referred to in TABLE 1, and elsewhere herein, the nomenclature used for the Temper of metal strip 114 is adapted from the Special Temper designation suggested by supplier. Thomas Steel Strip Corporation, Warren, Ohio, from whom metal strip 114 used in the invention can be obtained. Such metal strip can also be obtained from Hille & Muller, Dusseldorf, Germany. Accordingly, the Temper designations "Temper 4" for the Comparative Prior Art Strip, and "Temper 3.5" for the metal strip 114 used in cathode cans used in the invention, represent the combination of physical properties illustrated in TABLE 1. In the temper designation system incorporated into TABLE 1, a lower Temper number generally represents a harder, less ductile material, while a higher Temper number generally represents a softer, more ductile material.

TABLE 1

| Property | Inv. Ex #1 | C Ex 1 |
|----------------------------------|------------|-----------|
| Temper Number | 3.5 | 4 |
| Grain Size. ASTM E112-88 | 7-12 | 9-12 |
| Yield Strength | 45-52 ksi | 32-45 ksi |
| Elongation, Min, 80-100 mm width | 25% | 35% |
| Hardness | 76-82 | 77-82 |
| Erichsen Ductility ASTM E643-84 | ≥7.5 mm | ≥9.5 mm |

[0063] As seen from the properties illustrated in TABLE 1, metal strip 114 preferred for cathode cans used in cells of the invention has a higher yield strength, less elongation, and is less ductile than conventional metal strips of e.g. Comparative Example 1. Grain size is also reduced to a degree.

[0064] The physical properties in TABLE 1 suggest that metal strip 114 is harder and less formable than conventional battery grade metal strip. Yet, battery-forming experiments show that the modified metal strip 114 is sufficiently ductile to tolerate making cathode cans using the methods disclosed herein.

[0065] The hardness and formability of the strip represent compromises between the need to be able to form the strip in making cathode can 44, and to crimp the distal edges of side wall 47 in closing the cell at final assembly, and the desire to obtain as much strength as possible in a minimum thickness. While reducing the thickness of strip 114, and while also making the strip harder and potentially somewhat reducing the formability of strip 114 as represented by reduced elongation and ductility values are features of the invention, the ability to form the strip is surprisingly preserved, and the strength of the cathode cans formed from the strip is surprisingly preserved at a sufficiently high level that the cans tolerate normal conditions of cell assembly and usage.

[0066] Accordingly, metal strip, tempered as above, and suitable for forming cathode cans of the invention for use in metal-air cells, may be preferably about .075 millimeter up to less than .14 millimeter thick, more preferably about .075 millimeter up to less than .11 millimeter thick, still more preferably about .075 millimeter up to less than .10 millimeter thick, yet more preferably .075 millimeter up to about .09 millimeter thick. In some instances, the thickness is from about .09 millimeter up to less than .10 millimeter.

[0067] Cathode cans suitable to the invention can be formed of virtually any core metal layer that is covered, on its opposing surfaces, with the appropriate metal, e.g. coating, plating or cladding, such appropriate covering having a hydrogen overvoltage similar to that of the corresponding electrode and being insoluble at high pH's (or in the presence of alkaline electrolyte), the metal plating or cladding being in chemical communication via the electrolyte with the electrode material, if not in direct physical contact therewith.

[0068] Optionally, the cathode can may be formed entirely of a metal or alloy having a hydrogen overvoltage similar to that of the electrode (as opposed to plating or cladding the can) so long as sufficient strength and ductility are available from the material selected. In addition to nickel, other exemplary suitable plating, cladding, or can materials are stainless steel, palladium, silver, platinum, and gold. Steel strip plated with nickel and nickel alloy is generally used because the cost is low, and because pre-plated steel strip, which generally requires no post-plating processes, is commercially available. The metal in the can must be ductile enough to withstand the drawing process, and strong enough to withstand the cell crimping and closure process.

[0069] Cathode cans, for example, may be made of cold-rolled steel plated with nickel. Steel strip pre-plated with nickel can also be used. Cathode cans may also be formed from cold-rolled mild steel, with at least the inside portions of the cans being subsequently post plated with nickel. Other examples of materials which can be used for cathode cans include nickel-clad stainless steel; nickel-plated stainless steel; INCONEL (INCO alloy of nickel, a non-magnetic alloy); pure nickel with minor alloying elements (NICKEL 200 and related family of NICKEL 200 alloys such as NICKEL

201, etc.), all available from Huntington Alloys, a division of INCO, Huntington, West Virginia. Some noble metals may also find use as plating, cladding, or can metals, including steel strip plated with nickel, and mild steel strip subsequently plated with nickel after forming the can.

[0070] In order to obtain the advantages of the Temper 3.5 metal strip, one, of course, must select appropriate materials and utilize proper metal processing steps, as illustrated above, to obtain the balance of properties of hardness and ductility which provide sufficient strength for the thinner can wall while tolerating the forming steps wherein the can is formed from the metal strip, and wherein the cathode can is crimped about seal 60 and the anode can. Given the above teaching of Temper and related properties, those skilled in the art can now apply the principles taught therein to a variety of related metals and structures.

The Anode Can

[0071] A typical anode can of the invention is plated with copper on its inner surface. Copper has an hydrogen over-voltage similar to that of zinc. The anode can is readily formed of stainless steel wherein the inner surface 32 is plated, clad, or otherwise covered with copper, and the outer surface 34 is plated, clad, or otherwise covered with nickel. As illustrated in FIGURE 7, typical anode cans comprise a metal strip 120 having a three-layer structure including a core layer 122 of e.g. 304 stainless steel, clad or plated on opposing surfaces with surface layers 124 and 126 of copper and nickel, respectively.

[0072] As with other aspects of this invention, the thickness of the metal strip 120 used to form the anode can is desirably reduced to a value less than thicknesses for conventionally known such elements.

[0073] In conventional metal strip material used to make anode cans, about 76 to 78 percent by volume of the metal is contained in the layer of stainless steel, about 16 percent by volume is contained in the inner copper layer, and about 8 percent by volume is contained in the outer nickel layer. Accordingly, with all expressions being percent by volume represented by the respective layers, the conventional structure can be expressed, layer for layer, as, for example,

/16% Cu/76% SS/8% Ni/.

[0074] The strength of the above metal strip structure is generally provided by a combination of (a) thickness of the structure, and (b) the combined strengths of the materials in the individual layers. Regarding materials, the stainless steel provides proportionately more strength than the copper or the nickel. In the invention, the thickness of metal strip 120 can be reduced while maintaining suitable strength and formability in the metal structure.

[0075] In the invention, the thickness "T" of metal strip 120 is from about 0.075 millimeter to less than 0.11 millimeter, preferably from about 0.09 millimeter to less than 0.11 millimeter, more preferably from about .10 millimeter up to less than .11 millimeter. To the extent thinner strip 120 can be used, additional space is available in anode cavity 38 for receiving anode material 26, whereby the use life of the cell is respectively improved.

[0076] Such reduction in thickness is accomplished in combination with increasing the fraction of the metal which is represented by the stainless steel layer 122. Such increase in the stainless steel fraction provides, relative to conventional cells, greater strength per unit of thickness of strip 120.

[0077] Increasing the stainless steel fraction correspondingly reduces the fraction of strip 120 represented by layers 124, 126, and also the absolute thicknesses of layers 124, 126. Surprisingly, operational integrity of these already very thin layers 124, 126 is maintained in spite of the additional thinning. Thus, a three-layer structure of the above nature, having the above combination of suitable forming properties along with sufficient strength, stiffness, and crush resistance in the anode can, can be made into anode cans when the relative amounts of the layers 122, 124, and 126 are revised to increase the relative amount of stainless steel layer 122.

[0078] The following structures illustrate that the fractional amount of stainless steel can be increased by up to about 17% over the conventional structures, namely from about 78% stainless steel to about 91% stainless steel. "Cu" is copper. "SS" is stainless steel. "Ni" is nickel. All expressions are percent by volume. Exemplary such structures are:

/16% Cu/82% SS/2% Ni/

/ 7% Cu/91% SS/2% Ni/

[0079] The above two structures of metal strip 120, for making anode cans of the invention, are merely illustrative of the full range of structures that can be made wherein the common feature is the increase in the amount of stainless steel relative to the amount of copper and/or nickel and corresponding decrease in relative amounts of copper and/or nickel. Preferably, the thicknesses of layers 124, 126 both decrease in proportion to the increase in thickness of layer 122.

[0080] Accordingly, the thickness of the copper layer can range from about 7% to about 16% of the volume of the three-layer metal strip, and the volume of the nickel layer can range from about 2% to about 7% by volume of the three-

layer metal strip. So long as the stainless steel content is increased above the conventionally known level of about 78%, the strength of the metal strip 120, for any given thickness, is improved. Thus, metal strip 120 of the invention allows for reduction in overall thickness of metal strip 120 while maintaining the strength of the anode can, and the operational integrity of layers 124, 126 to conduct electric current associated with operation of an electrochemical cell made with such anode can.

[0081] Preferred steps in the development of structures having increasing amounts of the stainless steel layer, and thus higher strength/thickness ratio, produce anode cans having progressively, all in percent by volume/thickness, 79% stainless steel, 80% stainless steel, 83% stainless steel, 87% stainless steel, and 91% stainless steel, with corresponding 21%, 20%, 17%, 13%, and 9% as the corresponding combined amounts of the copper and nickel layers 124 and 126. Preferred steps in development of structures for metal strip 120 having decreasing amounts of the copper layer 124 are, all in percent by volume/thickness, 15% copper, 11% copper, and 7% copper. Preferred steps in development of structures having decreasing amounts of the nickel layer 126 are, all in percent by volume/thickness, 7% nickel, 6% nickel, 3% nickel, and 2% nickel.

[0082] Where core layer 122 is 91% by volume of the thickness, and assuming a total of three layers, the combination of the copper and nickel layers is correspondingly 9% by volume of the thickness. Where the core layer is 79% by volume of the thickness, and assuming a total of three layers, the combination of the copper and nickel layers is correspondingly 21% by volume of the thickness.

[0083] The full range of the structures specified can be obtained from Sumitomo Metals Company, Japan. The most preferred such structure has the designation "high strength CSTN-12," an annealed and work-hardened product.

[0084] The can structures, whether the anode can or the cathode can, can include more than 3 layers. The additional layer or layers can be on the outside of the respective nickel and/or copper layers, or can be between the respective nickel and/or copper layers and the respective e.g. stainless steel or cold rolled steel layer.

[0085] As illustrated in the drawings, the structure of the anode can is arranged and configured such that, when a closing force is applied to thereby crimp the side wall of the cathode can inwardly against the seal at cell closing, the anode can side wall bears a corresponding force along a top-to-bottom height of side wall 30, opposing the closing force.

VOLUME EFFICIENCIES

[0086] The volume efficiencies of cells of the invention are obtained as a result of the combination of numerous reductions in space usage for various of the non-reactive elements of the cell, primarily structural elements inside the cell related to the second portion of space 12. FIGURE 8 shows a cross-section of a cell wherein the left half of the cell uses conventional thicker materials of construction while the right half of the cell uses the thinner materials of construction disclosed herein, illustrating the greater volume which can be gained for use in containing additional electrochemically reactive anode material 26 e.g. anodic zinc paste. As illustrated in FIGURE 8, in cells of the invention, thicknesses have been reduced at least in one or more, preferably all of the following - anode can 24, cathode can 44, cathode assembly 42, and seal 60.

[0087] Table 2 gives data regarding various non-reactive elements of cells of the invention, illustrating the Volume Efficiencies obtained thereby. The volume efficiencies obtained in the invention readily translate into corresponding increases in the overall potential milliampere-hour capacities of the corresponding cells.

[0088] Sizes referred to in Table 2 represent designations of the IEC. For Examples 2 and 3, along with Comparative Examples 4-8, the cell Overall Volume is about .55 cm³ and the ratio of Overall Height to Overall Diameter is about 0.45/1. For Examples 9 and 10, along with Comparative Examples 11-15, the cell Overall Volume is about .25 cm³ and the ratio of Overall Height to Overall Diameter is about 0.68/1. For Examples 16 and 17, along with Comparative Examples 18-22, the cell Overall Volume is about .16 cm³ and the ratio of Overall Height to Overall Diameter is about 0.44/1. For Examples 23 and 24, along with Comparative Examples 25-26, the cell Overall Volume is about .09 cm³ and the ratio of Overall Height to Overall Diameter is about 0.59/1.

[0089] Overall Volume for both the Examples of the invention and the Comparative Examples is calculated using average height and diameter for the respective size, based on IEC standards, and assuming a right cylinder configuration as illustrated in FIGURE 2.

[0090] The term "Volume Efficiency" means the fraction of the overall volume, generally referred to as a decimal fraction, which is defined by cavity 38. Thus, for a given overall cell size, cell volume, the larger is cavity 38, the higher is the Volume Efficiency of the cell.

[0091] Volume Efficiency is expressed as a fraction of the Overall Volume of the cell, Volume Efficiency being measured as the composite of thin horizontal slices of the cell, top to bottom, where each slice is e.g. 0.5 millimeter thick.

TABLE 2

| | | | | | | | | | |
|----|--|----------------------|-------------|-------------|--------------|--------------|--------------|--------------|--------------|
| 5 | | SIZE PR44 | | | | | | | |
| | | <u>Data Measured</u> | <u>Ex 2</u> | <u>Ex 3</u> | <u>C Ex4</u> | <u>C Ex5</u> | <u>C Ex6</u> | <u>C Ex7</u> | <u>C Ex8</u> |
| | | Overall Height* | .2070 | .2070 | .2070 | .2070 | .2070 | .2070 | .2070 |
| 10 | | Overall Dia*1 | .4550 | .4550 | .4550 | .4550 | .4550 | .4550 | .4550 |
| | | Overall Vol** | .5515 | .5515 | .5515 | .5515 | .5515 | .5515 | .5515 |
| | | Anode Top*2 | .0050 | .0075 | .0100 | .0102 | .0075 | .0100 | .0088 |
| | | AnodeSidewall*2 | .0050 | .0075 | .0100 | .0100 | .0093 | .0235 | .0088 |
| 15 | | Seal Sidewall*2 | .0040 | .0100 | .0105 | .0108 | .0085 | .0092 | .0121 |
| | | Cathode Can*2 | .0047 | .0065 | .0080 | .0100 | .0070 | .0087 | .0104 |
| | | Seal Foot*2 | .0270 | .0287 | .0305 | .0383 | .0285 | .0429 | .0376 |
| 20 | | Cathode*2 | .0100 | .0126 | .0142 | .0152 | .0171 | .0169 | .0264 |
| | | To 1st Radius*3 | .1395 | .1373 | .1395 | .1238 | .0965 | .1529 | .1277 |
| | | Anode Top*1 | .2870 | .2851 | .2780 | .3005 | .2812 | .2774 | .3070 |
| | | Anode Volume** | .3915 | .3456 | .3177 | .3039 | .3102 | .3106 | .2875 |
| 25 | | Vol Efficiency | 71% | 63% | 58% | 55% | 56% | 56% | 52% |

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SIZE PR48

| | <u>Data Measured</u> | <u>Ex 9</u> | <u>Ex10</u> | <u>C Ex11</u> | <u>C Ex12</u> | <u>C Ex13</u> | <u>C Ex14</u> | <u>C Ex15</u> |
|----|----------------------|-------------|-------------|---------------|---------------|---------------|---------------|---------------|
| 5 | Overall Height* | .2070 | .2070 | .2070 | .2070 | .2070 | .2070 | .2070 |
| | Overall Dia*1 | .3050 | .3050 | .3050 | .3050 | .3050 | .3050 | .3050 |
| | Overall Vol** | .2478 | .2478 | .2478 | .2478 | .2478 | .2478 | .2478 |
| 10 | Anode Top*2 | .0050 | .0060 | .0080 | .0097 | .0069 | .0073 | .0061 |
| | AnodeSidewall*2 | .0050 | .0060 | .0080 | .0107 | .0082 | .0134 | .0126 |
| | Seal Sidewall*2 | .0040 | .0078 | .0090 | .0062 | .0082 | .0081 | .0129 |
| | Cathode Can*2 | .0047 | .0080 | .0080 | .0094 | .0068 | .0077 | .0076 |
| 15 | Seal Foot*2 | .0240 | .0263 | .0291 | .0317 | .0289 | .0376 | .0238 |
| | Cathode*2 | .0100 | .0142 | .0157 | .0264 | .0247 | .0219 | .0230 |
| | To 1st Radius*3 | .1273 | .1221 | .1273 | .1292 | .1146 | .1462 | .1499 |
| 20 | Anode Top*1 | .1740 | .1740 | .1608 | .1782 | .1560 | .1798 | .1826 |
| | Anode Volume** | .1586 | .1344 | .1235 | .1157 | .1180 | .1278 | .1239 |
| | Vol Efficiency | 64% | 54% | 50% | 47% | 48% | 52% | 50% |

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SIZE PR41

| | <u>Data Measured</u> | <u>Ex 16</u> | <u>Ex 17</u> | <u>C Ex18</u> | <u>C Ex19</u> | <u>C Ex20</u> | <u>C Ex21</u> | <u>C Ex22</u> |
|----|----------------------|--------------|--------------|---------------|---------------|---------------|---------------|---------------|
| 30 | Overall Height* | .1350 | .1350 | .1350 | .1350 | .1350 | .1350 | .1350 |
| | Overall Dia*1 | .3050 | .3050 | .3050 | .3050 | .3050 | .3050 | .3050 |
| | Overall Vol** | .1616 | .1616 | .1616 | .1616 | .1616 | .1616 | .1616 |
| | Anode Top*2 | .0050 | .0061 | .0080 | .0076 | .0068 | .0058 | .0058 |
| 35 | AnodeSidewall*2 | .0050 | .0061 | .0080 | .0173 | .0143 | .0108 | .0129 |
| | Seal Sidewall*2 | .0040 | .0067 | .0093 | .0083 | .0085 | .0079 | .0095 |
| | Cathode Can*2 | .0047 | .0080 | .0080 | .0099 | .0065 | .0075 | .0081 |
| 40 | Seal Foot*2 | .0233 | .0209 | .0227 | .0379 | .0312 | .0294 | .0217 |
| | Cathode*2 | .0100 | .0118 | .0123 | .0258 | .0233 | .0221 | .0250 |
| | To 1st Radius*3 | .0597 | .0597 | .0542 | .0791 | .0663 | .0804 | .0818 |
| | Anode Top*1 | .1700 | .1746 | .1738 | .1717 | .1582 | .1763 | .1548 |
| 45 | Anode Volume** | .0887 | .0785 | .0718 | .0611 | .0647 | .0721 | .0680 |
| | Vol Efficiency | 55% | 49% | 44% | 38% | 40% | 45% | 42% |

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SIZE PR70

| | <u>Data Measured</u> | <u>Ex 23</u> | <u>Ex 24</u> | <u>C Ex25</u> | <u>C Ex26</u> |
|----|----------------------|--------------|--------------|---------------|---------------|
| 5 | Overall Height* | .1350 | .1350 | .1350 | .1350 |
| | Overall Dia*1 | .2280 | .2280 | .2280 | .2280 |
| | Overall Vol** | .0903 | .0903 | .0903 | .0903 |
| 10 | Anode Top*2 | .0050 | .0060 | .0060 | .0080 |
| | AnodeSidewall*2 | .0050 | .0060 | .0060 | .0080 |
| | Seal Sidewall*2 | .0040 | .0063 | .0113 | .0101 |
| | Cathode Can*2 | .0047 | .0060 | .0080 | .0083 |
| 15 | Seal Foot*2 | .0233 | .0246 | .0266 | .0264 |
| | Cathode*2 | .0100 | .0100 | .0100 | .0258 |
| | To 1st Radius*3 | .0723 | .0752 | .0752 | .0641 |
| 20 | Anode Top*1 | .1250 | .1151 | .1151 | .1186 |
| | Anode Volume** | .0506 | .0436 | .0377 | .0331 |
| | Vol Efficiency | 56% | 48% | 42% | 37% |

* = Dimension in Inches

** = Dimension in Cubic Centimeters

1 = Diameter

2 = Thickness

3 = Height

[0092] FIGURE 9 is a graphical representation, with logarithmic scale on the X-axis, of the Volume Efficiencies shown in Table 2. The "X's" in FIGURE 9 represent Volume Efficiencies of the Comparative Example cells. The "o's" represent

Volume Efficiencies of the cells of respective Examples 2, 9, 16, and 23.

[0093] Examples 2, 9, 16, and 23 represent generally the upper portion of the range of volume efficiencies that can be achieved using the teachings herein, wherein the upper portion of the range is generally represented by the equation shown as a first line in FIGURE 10 and expressed as

$$.77 + \text{Log}^{10}(\text{Overall Volume}) \cdot .20.$$

[0094] Linear Regression Analysis of the values represented by Examples 2, 9, 16, and 23 is shown as a second line in FIGURE 13, represented by the equation

$$.80 + \text{Log}^{10}(\text{Overall Volume}) \cdot .281.$$

[0095] A third line, generally connecting the points for Examples 2 and 16, suggests an equation of

$$.77 + \text{Log}^{10}(\text{Overall Volume}) \cdot .28.$$

[0096] A fourth line, representing the equation

$$.69 + \text{Log}^{10}(\text{Overall Volume}) \cdot .22$$

represents generally an incremental step in improving Volume Efficiency, using the concepts of the invention.

[0097] The equation

$$.65 + \text{Log}^{10}(\text{Overall Volume}) \cdot .20$$

generally represents a line showing a minimum improvement over all prior art cells.

[0098] Table 3 gives representative values for the several equations used in FIGURE 13 at the size designations given in Table 3.

TABLE 3

| Equation Valued | PR44 | PR48 | PR41 | PR70 |
|---|-------|-------|-------|-------|
| $.77 + \text{Log}^{10}(\text{Overall Volume}) \cdot .20$ | .7184 | .6489 | .6119 | .5608 |
| $.80 + \text{Log}^{10}(\text{Overall Volume}) \cdot .281$ | .7275 | .6298 | .5779 | .5061 |
| $.77 + \text{Log}^{10}(\text{Overall Volume}) \cdot .28$ | .6977 | .6004 | .5487 | .4772 |
| $.69 + \text{Log}^{10}(\text{Overall Volume}) \cdot .22$ | .6332 | .5568 | .5161 | .4599 |
| $.65 + \text{Log}^{10}(\text{Overall Volume}) \cdot .20$ | .5984 | .5289 | .4919 | .4408 |

[0099] Especially referring, now, to size PR41 cells, some improvement is seen at Volume Efficiencies below those represented by the equation $.65 + \text{Log}^{10}(\text{Overall Volume}) \cdot .20$.

[0100] While the equation $.65 + \text{Log}^{10}(\text{Overall Volume}) \cdot .20$ represents a general lower end of the range of improvements which can be obtained using principles of the invention, the invention provides incremental improvements based on the degree to which space is recovered for use in cavity 38. Where only small amounts of space are recovered, the improvement in Volume Efficiency is correspondingly smaller. Where larger amounts of space are recovered, the improvement is larger. Thus, the Volume Efficiency for a given cell depends on the degree to which the Efficiency-boosting measures of the invention are implemented. Where only nominal measures are taken, Volume Efficiency will be closer to the line represented by the equation

$$.65 + \text{Log}^{10}(\text{Overall Volume}) \cdot .20.$$

To the extent more extensive measures are taken, Volume Efficiency will be closer to the line represented by the equation

$$.77 + \text{Log}^{10}(\text{Overall Volume}) \cdot .20,$$

and where thickness reductions are pushed to the limits given for each non-reactive element of the cell, Volume Efficiencies can be slightly higher than those represented by the last recited equation, whereby the equation is not absolutely limiting of the Volume Efficiencies which can be obtained using the principles of the invention.

[0101] All Volume Efficiencies between the lines represented by the last two above equations are contemplated by the invention, generally across all the cell sizes shown, and all sizes which can be extrapolated, both from the data in Table 3 and from the equations given above.

[0102] As seen in FIGURE 9, the Volume Efficiencies of the Comparative Examples all fall below a line represented by the equation

$$.65 + \text{Log}^{10}(\text{Overall Volume}) \cdot .20.$$

[0103] Those skilled in the art will now see that certain modifications can be made to the cells and their elements, and methods for making and using them, herein disclosed with respect to the illustrated embodiments, without departing from the spirit of the instant invention. And while the invention has been described above with respect to the preferred embodiments, it will be understood that the invention is adapted to numerous rearrangements, modifications, and alterations, and all such arrangements, modifications, and alterations are intended to be within the scope of the appended claims.

Claims

1. An anode can for use in an electrochemical cell, said anode can having a top wall, and a first circumferential side wall extending downwardly from said top wall, said anode can having a first outer surface disposed outwardly on said top wall and outwardly on said first side wall, and an inner surface disposed inwardly on said top wall and inwardly on said first side wall, said anode can comprising a thickness thereof between the first outer and second inner surfaces, said anode can further comprising a first layer such as nickel, a second layer such as copper, and

a third layer comprising steel such as stainless steel between said first and second layers, characterized by said third layer comprising about 79 percent by volume to about 91 percent by volume of the overall thickness of at least one of said top wall and said first side wall of said anode can, and the thickness between the first outer and second inner surfaces comprising about 0.075 millimeter up to less than about 0.11 millimeter, and for example said first and second layers, in combination comprising about 9 percent by volume to about 21 percent by volume of said anode can.

2. An anode can according to claim 1, said third layer comprising about 83 percent by volume to about 91 percent by volume of said anode can, preferably about 87 percent by volume to about 91 percent by volume of said anode can.

3. An anode can according to claim 1 or claim 2, wherein said first layer comprises about 2 percent by volume to about 7 percent by volume of said anode can, said second layer comprising about 7 percent by volume to about 16 percent by volume of said anode can, and preferably said first layer comprises about 2 percent by volume to about 6 percent by volume of said anode can, said second layer comprising about 7 percent by volume to about 11 percent by volume of said anode can.

4. An anode can according to any of claims 1 to 3, wherein the thickness is from about 0.09 millimeter up to less than about 0.11 millimeter, and preferably from about 0.10 millimeter up to less than about 0.11 millimeter.

5. An electrochemical cell having an anode, a cathode, an electrolyte and a barrier layer between said anode and said cathode, said anode comprising an anode can according to any of claims 1 to 4, said cathode comprising a cathode can, joined with said anode can, and a seal between said anode can and said cathode can, said cathode can having an outer surface disposed outwardly on said electrochemical cell and an inner surface disposed inwardly in said electrochemical cell, said cathode can comprising a thickness between said inner and outer surfaces, said thickness being between about 0.075 millimeter and about 0.14 millimeter, preferably from about 0.075 millimeter up to less than about 0.10 millimeter, and more preferably from about 0.09 millimeter up to less than 0.10 millimeter.

6. An air depolarized electrochemical cell having an anode, a cathode, an electrolyte, and a barrier between said anode and said cathode, said anode comprising an anode can according to any of claims 1 to 4, said cathode comprising a cathode can joined with said anode can, and a seal between said anode can and said cathode can, said cathode can comprising a bottom wall and an upstanding side wall extending upwardly from said bottom wall, said anode can and said cathode can, in combination, defining a top and a bottom of said air depolarized electrochemical cell, an overall height between the top and the bottom, and a maximum diameter of said air depolarized cell defined by said side wall of said cathode can, the overall height and the maximum diameter, in combination, defining a right cylinder representing an overall volume of said air depolarized cell, of between about 0.06 cm³ and about 0.60 cm³.

7. An air depolarized electrochemical cell, comprising an anode, including an anode can and anode material in said anode can, said anode can having a top wall, and a first circumferential side wall extending downwardly from said top wall, said anode can having a first outer surface disposed outwardly on said top wall and outwardly on said first side wall, and a second inner surface disposed inwardly on said top wall and inwardly on said first side wall, said anode can comprising a thickness, between said first outer and said second inner surfaces, on at least one of said top wall and said first side wall; a cathode, including a cathode can, and a cathode assembly in said cathode can, said cathode can having a bottom wall, and a second circumferential side wall extending upwardly from said bottom wall; a seal between said anode can and said cathode can; and an electrolyte, said anode can and said cathode can, in combination, defining a top and a bottom of said air depolarized electrochemical cell, an overall height between the top and the bottom, and a maximum diameter of said air depolarized electrochemical cell, wherein the ratio of the overall height to the maximum diameter is about 0.25/1 to about 0.80/1, and the thickness between the first outer and second inner surfaces is about 0.075 millimeter up to less than 0.11 millimeter, preferably about 0.09 millimeter up to less than about 0.11 millimeter.

8. An air depolarized electrochemical cell according to claim 7, wherein said anode can comprises a first layer comprising nickel, a second layer comprising copper, and a third layer comprising stainless steel between said first and second layers, said third layer comprising about 79 percent to about 91 percent by volume of the overall thickness of at least one of said top wall and said first side wall of said anode can, and preferably said first and second layers, in combination, comprising about 9 percent by volume to about 21 percent by volume of said anode can.

9. An air depolarized electrochemical cell according to claim 7 or claim 8, wherein said third layer comprises about 83

percent by volume to about 91 percent by volume of said anode can, preferably about 87 percent by volume to about 91 percent by volume of said anode can.

- 5 10. An air depolarized electrochemical cell according to any of claims 7, 8 or 9, wherein said cathode can having an outer surface of said bottom wall and said side wall disposed outwardly on said electrochemical cell and an inner surface of said bottom wall and said side wall disposed inwardly in said electrochemical cell, said cathode can comprising a second thickness between the inner and outer surfaces of said side wall, and a third thickness between the inner and outer surfaces of said bottom wall, at least one of the second and third thicknesses being between about 0.075 millimeter and about 0.14 millimeter, preferably between about 0.075 millimeter and about 0.13 millimeter, and more preferably from about 0.09 millimeter up to less than 0.10 millimeter.
- 15 11. An air depolarized electrochemical according to any of claims 6 to 10, wherein said anode can and said cathode can, in combination, define a top and a bottom of said electrochemical cell, an overall height between the top and the bottom of said cell, and a maximum diameter of said cell, the ratio of the overall height to the maximum diameter being about 0.25/1 to about 0.80/1.
- 20 12. An electrochemical cell according to any of claims 5 to 11, wherein the side wall of said anode can is arranged and configured such that, when a closing force is applied to thereby crimp said side wall of said cathode can inwardly against said seal at cell closing, said anode can side wall bears a corresponding force along a top-to-bottom height thereof opposing the closing force.
- 25 13. An air-depolarized electrochemical cell, comprising an anode, including an anode can and anode material in said anode can, said anode can having a top wall, and a first circumferential side wall extending downwardly from said top wall, said first side wall having a first height generally corresponding to an overall second height of said anode can; a cathode, including a cathode can, said cathode can having a bottom wall and a second circumferential side wall extending upwardly from said bottom wall and terminating at a distal edge thereof, said second side wall having a third height generally corresponding to an overall fourth height of said cathode can, said cathode can comprising a substrate, said substrate, as taken at a location away from said distal edge, comprising first and second layers comprising nickel, and a third layer comprising steel between said first and second layers, said cathode further comprising an air cathode assembly in said cathode can, said cathode can having a third outer surface disposed outwardly on said bottom wall and outwardly on said second side wall, a fourth inner surface disposed inwardly on said bottom wall and inwardly on said second side wall, and a thickness between the third outer surface and the fourth inner surface, at one of said bottom wall and said second side wall, said anode, including said anode can and said anode material being received inside said cathode can such that said second side wall is disposed radially outwardly of said first side wall; an electrolyte; and a seal between said first and second side walls, said second side wall of said cathode can being crimped inwardly against said seal material, and by way of said seal material against an upper portion of said anode can, wherein the second height of said anode can side wall is significantly greater than one half the fourth height of said second side wall of said cathode can, and the thickness between the first outer and second inner surfaces comprising about 0.075 millimeter up to less than 0.10 millimeter; and/or said cathode can has a thickness between the third outer and the fourth inner surfaces, at one of said bottom wall and said second side wall, of about 0.075 millimeter to about 0.09 millimeter; and/or said anode can has a thickness between the first outer and second inner surfaces of about 0.075 millimeter up to less than 0.11 millimeter.
- 45 14. An air depolarized electrochemical cell according to any of claims 7 to 10 or 13, wherein said anode can and said cathode can, in combination define a top and a bottom of said electrochemical cell, a fifth height between the top and the bottom, and a maximum diameter of said electrochemical cell defined by said second side wall, the fifth height and the maximum diameter, in combination, defining a right cylinder, representing an overall volume of said electrochemical cell, of between about 0.06cm³ and about 0.60 cm³.
- 50 15. An air depolarized electrochemical cell according to claim 13 or claim 14, wherein said anode can and said cathode can, in combination, defining a top and a bottom of said electrochemical cell, a fifth height between the top and the bottom, and a maximum diameter of said electrochemical cell defined by said second side wall, the fifth height and the maximum diameter, in combination, defining a right cylinder, representing an overall volume of said electrochemical cell either of about 0.20 cm³ to about 0.30 cm³, the ratio of the volume of the cavity in said anode can to the overall volume of said electrochemical cell being at least 0.53/1, or of about 0.12 cm³ to about 0.20³, the ratio of the volume of the cavity in said anode can to the overall volume of said electrochemical cell being at least 0.46/1.
- 55 16. An air depolarized electrochemical cell according to claim 13 or claim 14, wherein said anode can has a first outer

surface on said top wall and said first side wall, and a second inner surface disposed inwardly on said top wall and said first side wall, the overall thickness of said first side wall between the first outer surface and the second inner surface being defined by a metal strip extending downwardly from said top wall and terminating at a second distal edge of the metal strip coincident with the first distal edge of said first side wall.

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17. An air depolarized electrochemical cell according to any of claims 5 and 14 to 16, wherein the ratio of the overall fifth height to the maximum diameter being about 0.25/1 to about 0.80/1.

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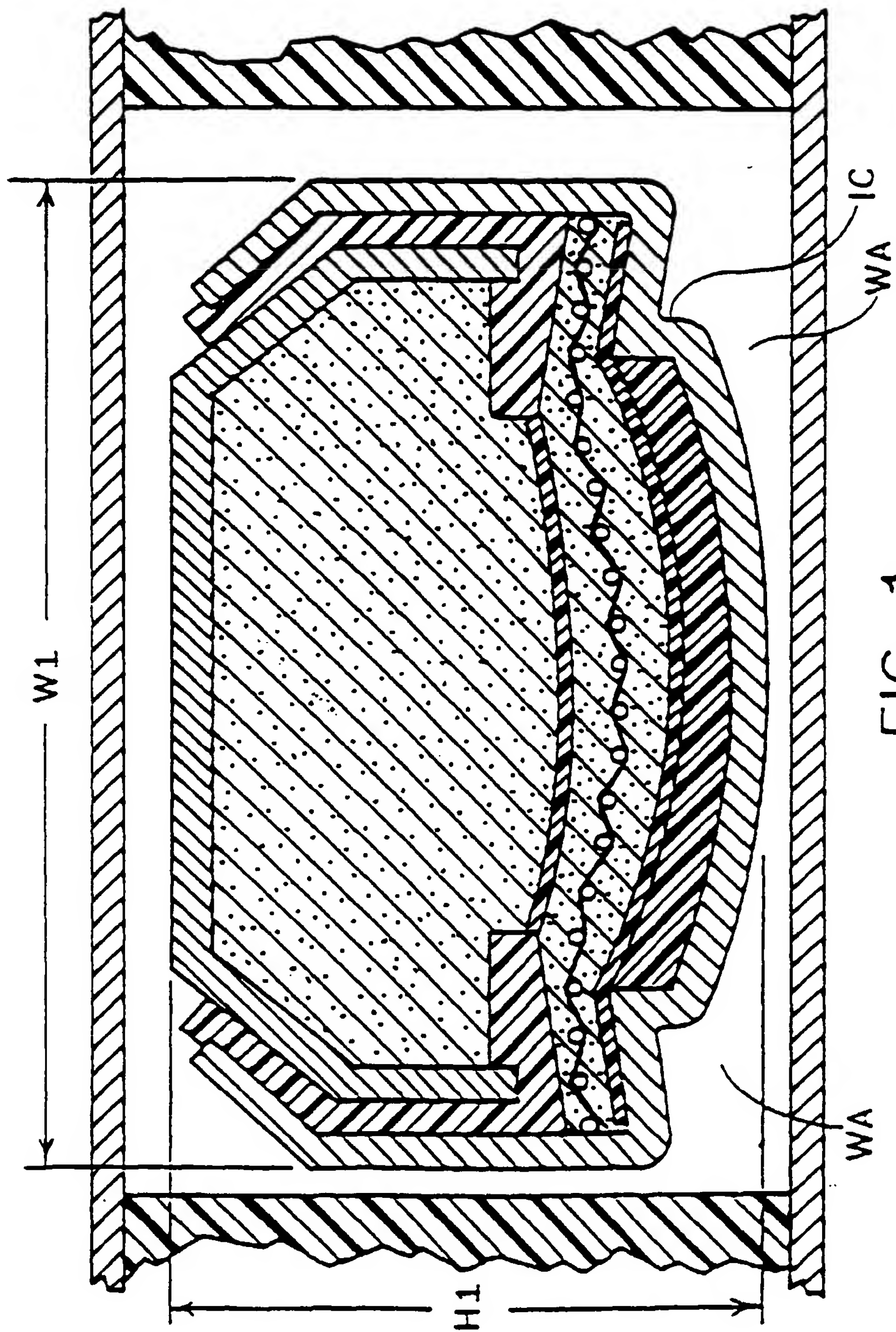


FIG. 1
(PRIOR ART)

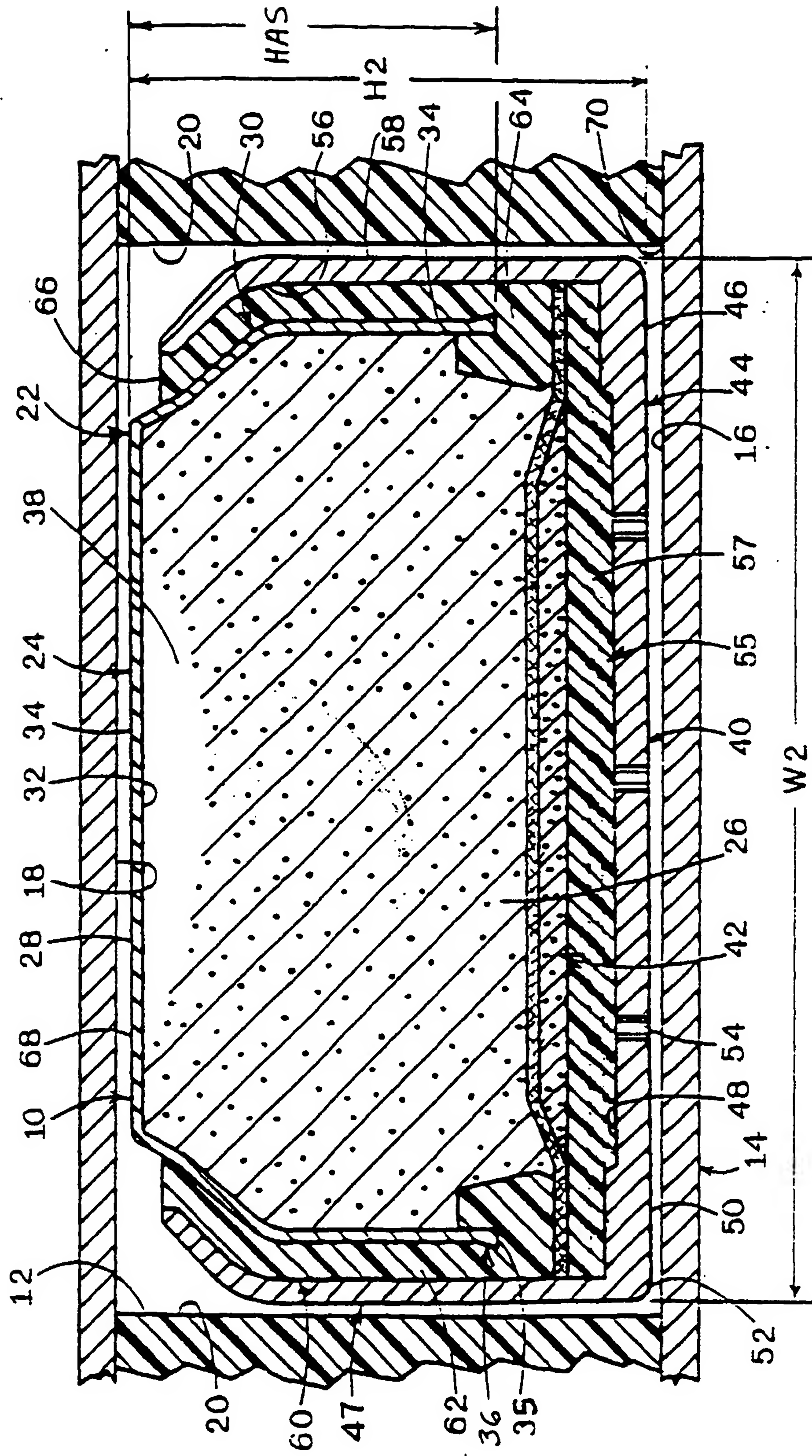


FIG. 2

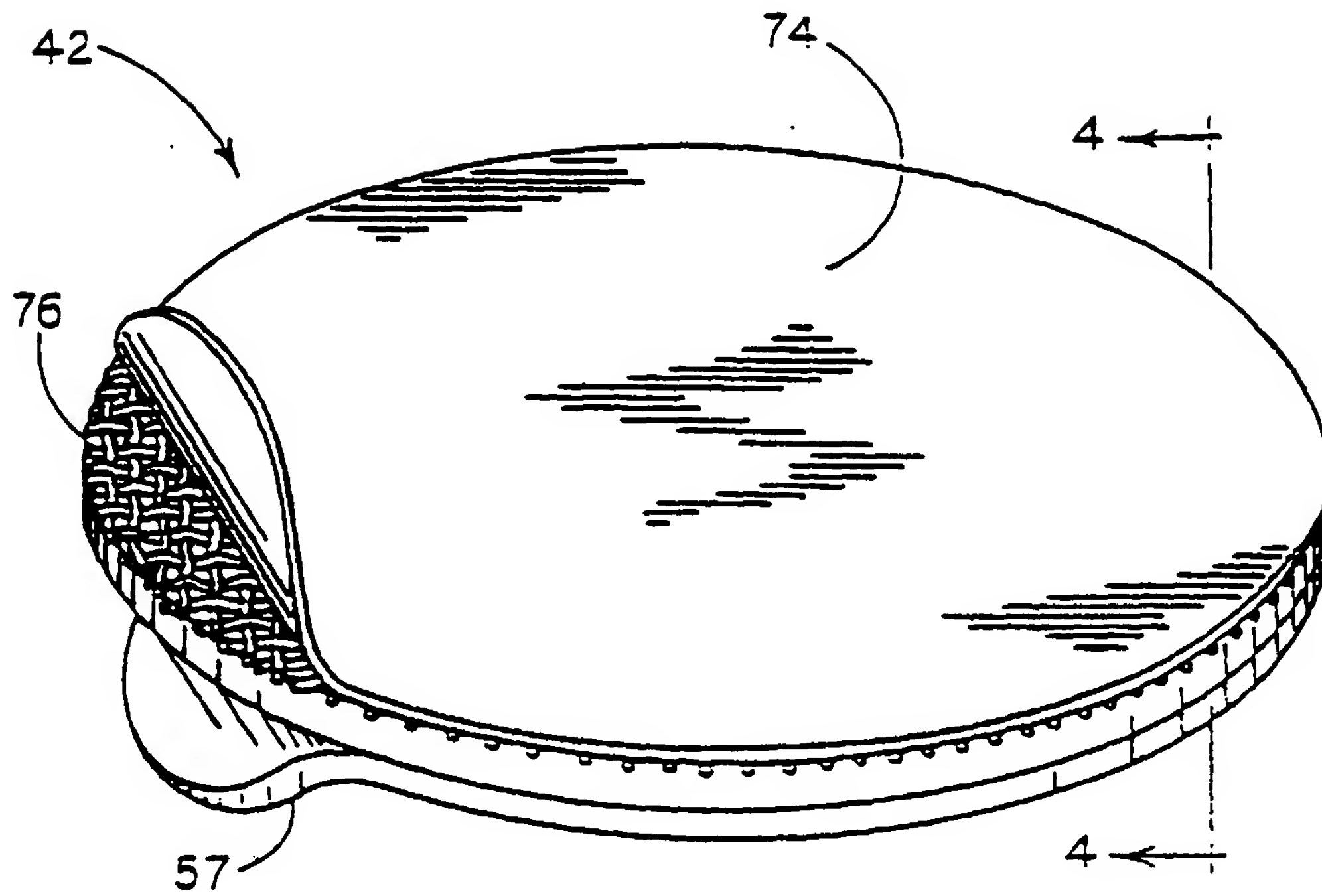


FIG. 3

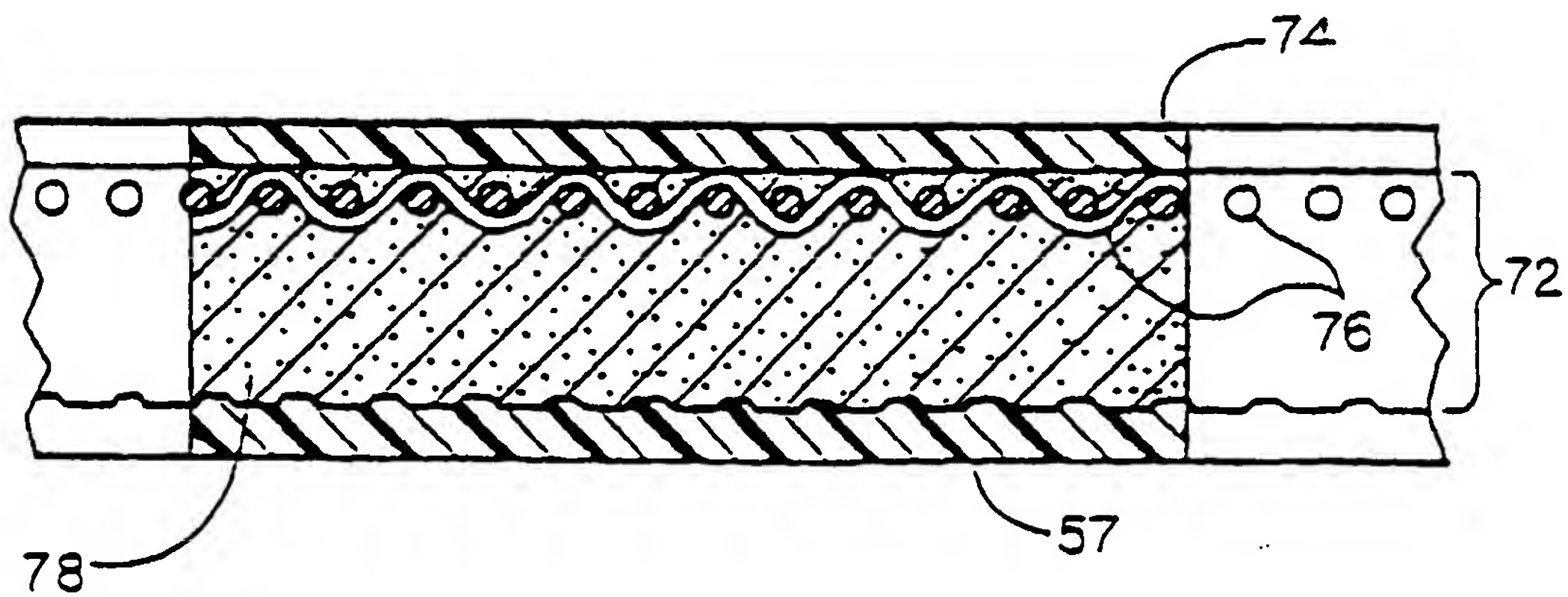


FIG. 4

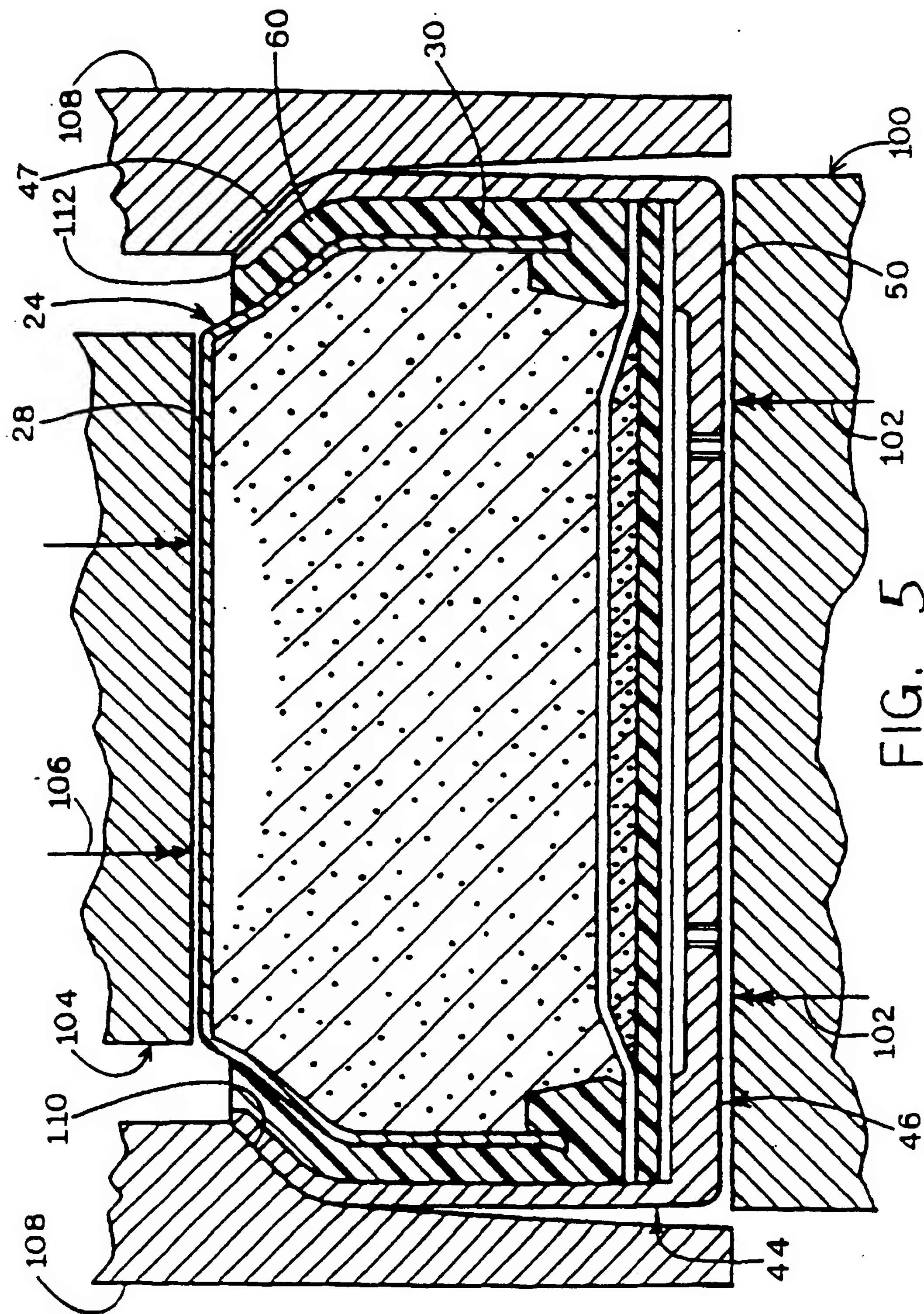


FIG. 5

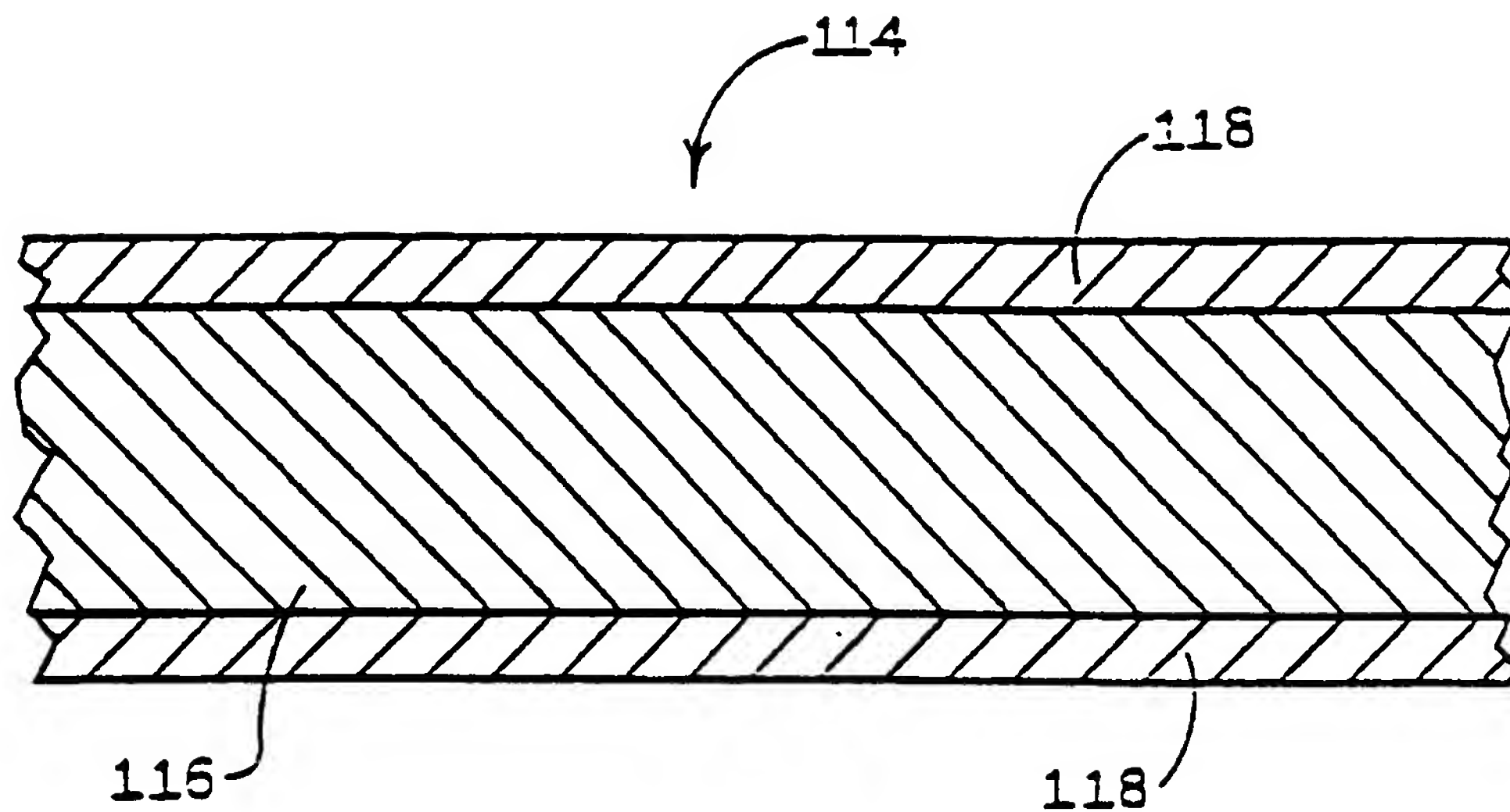


FIG. 6

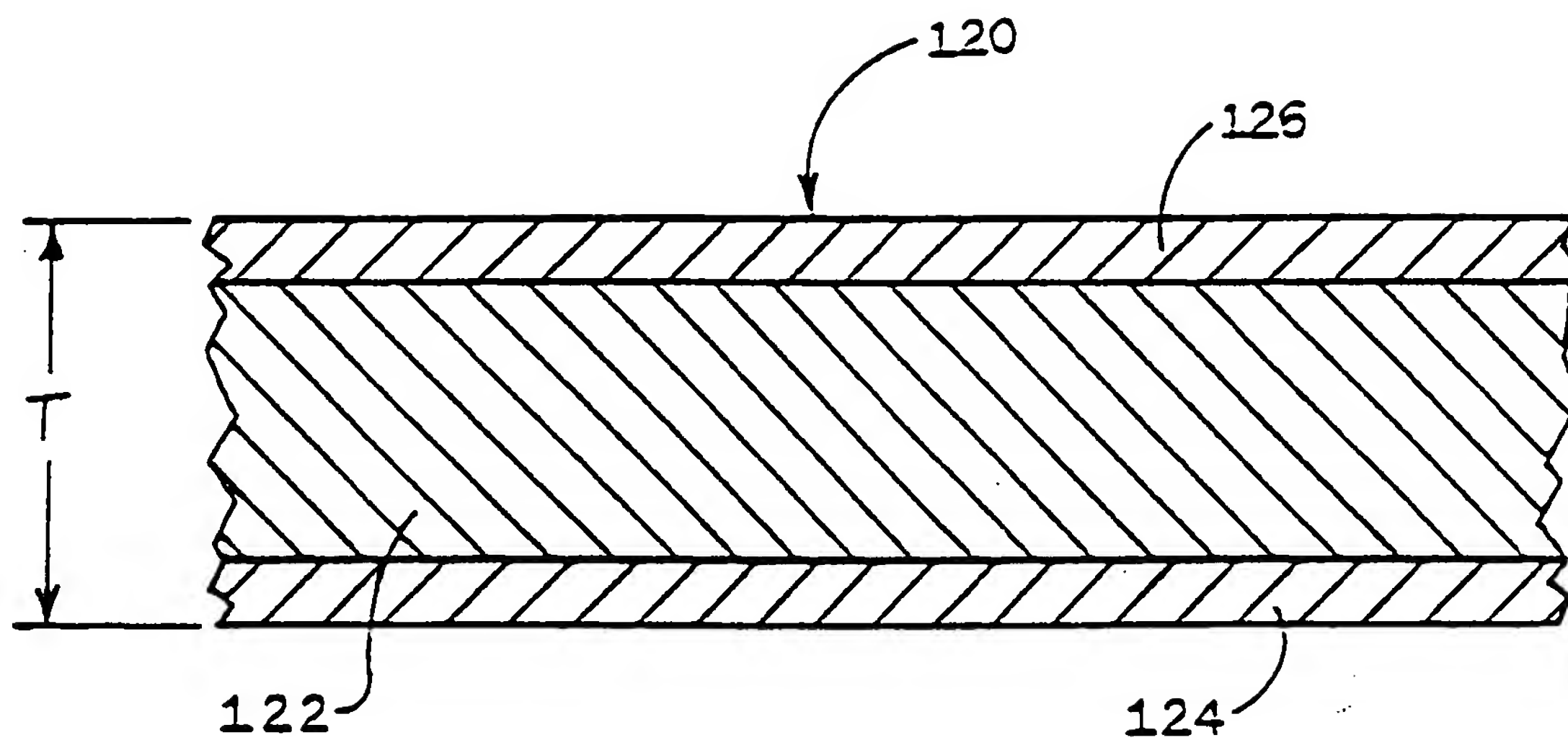


FIG. 7

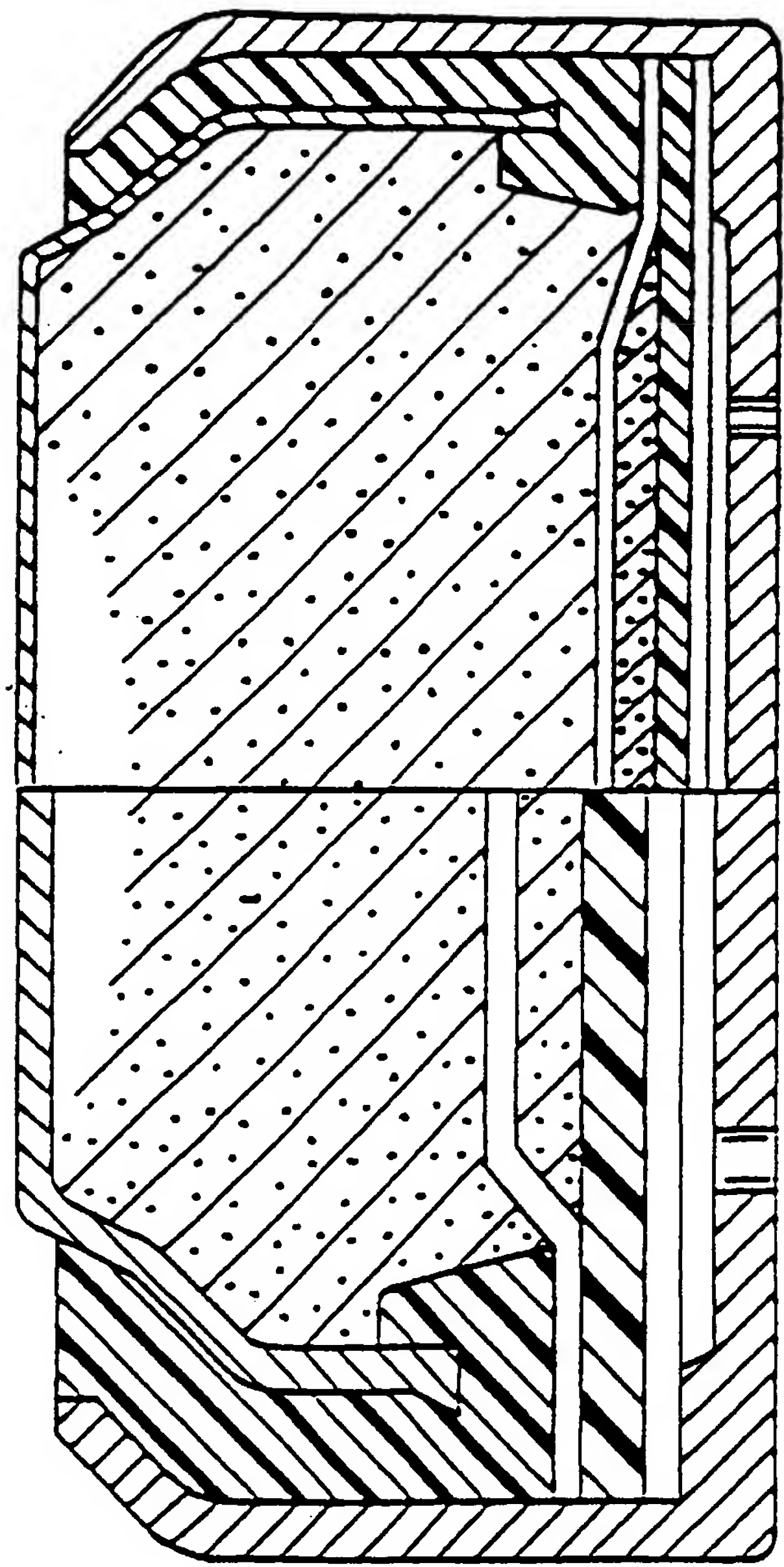
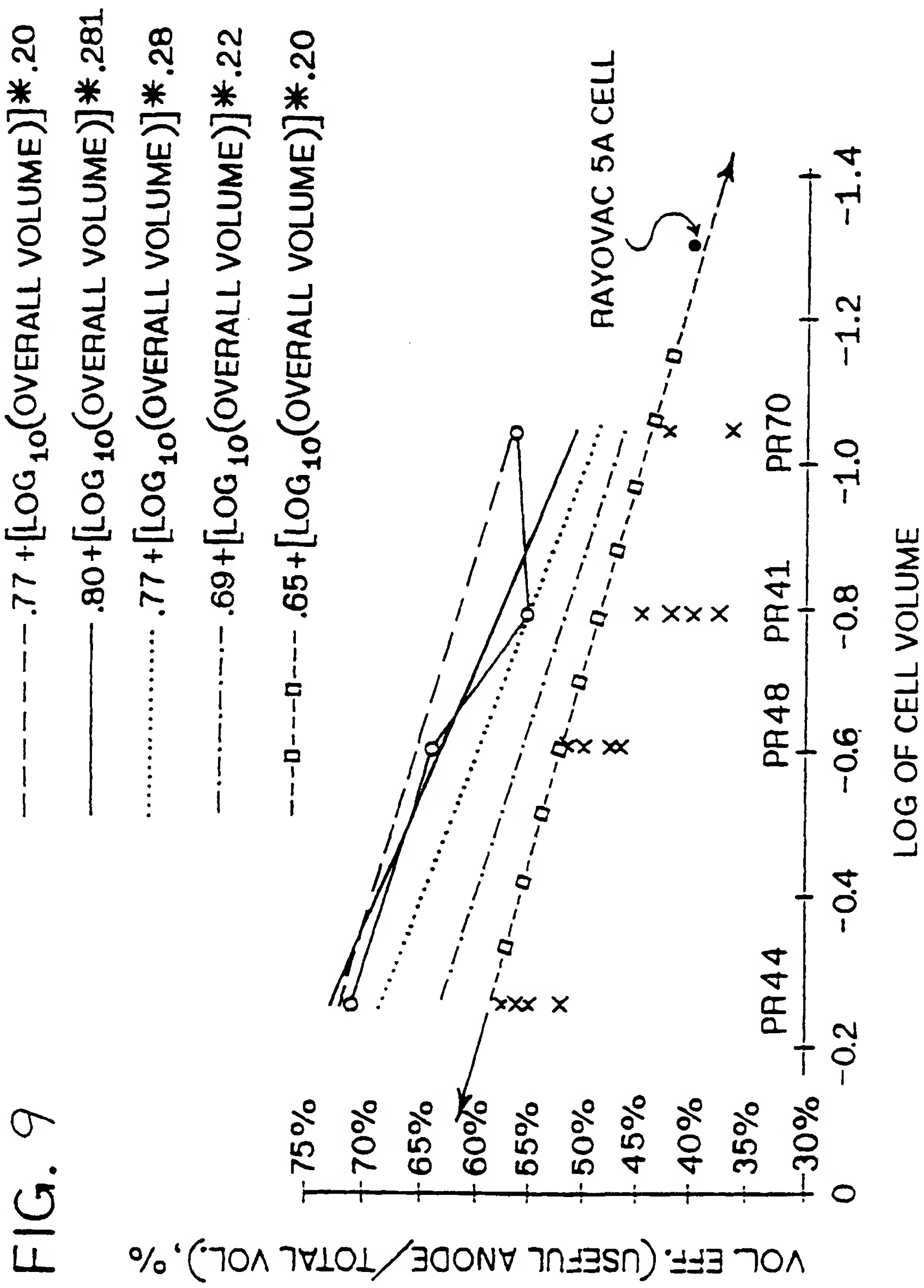


FIG. 8





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 30 7052

| DOCUMENTS CONSIDERED TO BE RELEVANT | | | |
|--|---|--|---|
| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int.Cl.6) |
| E | US 5 804 327 A (OLTMAN JOHN EDWARD) 8 September 1998 * column 4, paragraph 33 - column 5, paragraph 26 * * column 6, line 57 - line 63 * * column 9, line 55 - line 67 * * column 11, line 13 - line 22 * * column 11, line 46 - line 60 * * column 12, line 39 - line 50 * * column 13, line 1 - line 48 * * claims 1-18; figure 8 * | 1-17 | H01M12/06 H01M2/02 |
| A | EP 0 741 427 A (RAY O VAC CORP) 6 November 1996 * page 2, line 5 - line 12 * * page 4, line 27 - line 49 * * page 5, line 12 - line 21 * * page 5, line 44 - line 53 * * page 6, line 4 - line 13 * * page 6, line 32 - page 7, line 14 * * page 7, line 21 - line 37 * * page 12, line 25 - line 38 * * page 13, line 1 - line 6 * * page 15, line 22 - line 31 * * page 16, line 7 - line 11 * * page 16, line 21 - line 47 * * claims 1-5; table 3 * | 1-15, 17 | TECHNICAL FIELDS SEARCHED (Int.Cl.6) H01M |
| A | EP 0 741 425 A (RAY O VAC CORP) 6 November 1996 * page 4, line 43 - page 5, line 8 * * page 5, line 36 - line 46 * * page 6, line 15 - line 46 * * page 7, line 10 - line 50 * * page 8, line 16 - line 54 * * page 13, line 47 - page 14, line 15 * * claims 3-6, 8, 10, 13; table 3 * | 1-15, 17 | |
| The present search report has been drawn up for all claims | | | |
| Place of search THE HAGUE | | Date of completion of the search 11 February 1999 | Examiner Gamez, A |
| CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document | | | |

EPO FORM 1503 03.82 (P04C01)



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EUROPEAN SEARCH REPORT

Application Number
EP 98 30 7052

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